JOINT METALLURGICAL SOCIETIES' MEETING IN EUROPE, 1955

Great Britain · Germany · Belgium · France · Sweden · Italy

List of Awards

Award of the following distinctions was announced and the presentations were made during the Joint Metallurgical Societies Meeting in Europe, June, 1955.

In LONDON at the Opening Plenary Session on 2nd June, 1955

Sir **Charles Bruce-Gardner,** Bt., President, announced the election to *Honorary Membership* of *The Iron and Steel Institute* of Dr. **Howard Biers,** Member of the American and European Committees, Mr. **William H. Eisenman,** Secretary of the American Society for Metals, and Dr. **Ernest O. Kirkendall,** Secretary of the American Institute of Mining and Metallurgical Engineers.

Dr. **Maurice Cook,** President, announced the election to *Honorary Life Membership* of *The Institute of Metals* of Mr. **Henry DeWitt Smith,** President of the American Institute of Mining and Metallurgical Engineers and Dr. **George Roberts,** President of the American Society for Metals.

Dr. **Clyde Williams,** Past President of the *American Institute of Mining and Metallurgical Engineers* and Mr. **William H. Eisenman,** Secretary of the *American Society for Metals,* presented *Honorary Life Memberships* in this Institute and Society to Sir **Charles Bruce-Gardner,** Bt., President, and Mr. **K. Headlam-Morley,** Secretary, of The Iron and Steel Institute, and to Dr. **Maurice Cook,** President, and Lt.-Col. **S. C. Guillan,** Secretary, of The Institute of Metals.

Sir **Charles Bruce-Gardner** announced that Scrolls of Honour, under Seal of The Iron and Steel Institute and The Institute of Metals, had been awarded by the Councils to a number of representatives of societies in the United States of America and on the Continent. A list of the recipients is given on p. 290.

In DÜSSELDORF at the Opening Plenary Session on 9th June, 1955

Professor Dr. Ing. **Hermann Schenck,** President, announced the election to *Non-resident Honorary Membership* of the *Verein deutscher Eisenhüttenleute* of Dr. **Howard Biers,** Dr. **Ernest O. Kirkendall,** and Dr. **George Roberts.**

Professor Dr. Ing. **Paul Brenner,** President, announced the election to *Honorary Membership* of the *Deutsche Gesellschaft für Metallkunde* of Mr. **Henry DeWitt Smith** and Mr. **William H. Eisenman.**

At a later function, Dr. **George Roberts** and Dr. **Ernest Kirkendall** presented *Honorary Life Memberships* in the *American Society for Metals* and the *American Institute of Mining and Metallurgical Engineers* to Professor Dr. **H. Schenck,** President, and Dr. **Kurt Thomas,** Director, of the Verein deutscher Eisenhüttenleute, and to Professor Dr. **P. Brenner,** President, and Dr. **Bernhard Trautmann,** Secretary, of the Deutsche Gesellschaft für Metallkunde.

In LIÈGE on 13th June, 1955

Monsieur **François Perot,** President of the Centre National de Recherches Métallurgiques, announced the election to *Honorary Membership* of the *Association des Ingénieurs sortis de l'École de Liège,* of Dr. **Howard Biers,** Mr. **William H. Eisenman,** Mr. **K. Headlam-Morley,** Dr. **Ernest O. Kirkendall,** Dr. **George Roberts,** and Mr. **H. DeWitt Smith.**

Dr. **George Roberts** presented *Honorary Life Memberships* in the *American Society for Metals* to Monsieur **François Perot,** President, and to Professor **Pierre Coheur,** Director, of the Centre National de Recherches Métallurgiques.

Dr. **Ernest Kirkendall** presented *Honorary Life Memberships* in the *American Institute of Mining and Metallurgical Engineers* to Monsieur **Arthur Decoux,** Vice-President of the Centre National de Recherches Métallurgiques and President of the Charleroi Section, and to Professor **Pierre Coheur.**

In PARIS at the Opening Plenary Session at the Sorbonne on 14th June, 1955

Monsieur **Raoul de Vitry,** President, presented *Silver Medals* and *Honorary Membership* of the *Société Française de Métallurgie* to Dr. **Howard Biers,** Mr. **William H. Eisenman,** Dr. **Ernest O. Kirkendall,** Dr. **George Roberts,** and Mr. **Henry DeWitt Smith.**

At a Reception at the Hôtel de Ville, the Vice-Mayor presented the *Silver Medal of the City of Paris* to Dr. **George Roberts** and Mr. **Henry DeWitt Smith.**

On the following day, Dr. **George Roberts** and Dr. **Ernest Kirkendall** presented *Honorary Life Memberships* in the *American Society for Metals* and the *American Institute of Mining and Metallurgical Engineers* to

Dr. **Howard Biers** and Mr. **Sven Fornander,** Director of Research, Jernkontoret.

In TURIN at the Opening Session of the Annual Meeting of the Associazione Italiana di Metallurgia on 20th June, 1955

Dr. **George Roberts** presented an *Honorary Life Membership* in the *American Society for Metals* to Dr. **Aldo Daccò,** President of the Italian Association.

SCROLLS OF HONOUR

The wording of the Scrolls of Honour presented by the Councils of The Iron and Steel Institute and The Institute of Metals is as follows:

"*The Joint Metallurgical Societies Meeting in Europe* 1955. *The Councils of The Iron and Steel Institute and The Institute of Metals who organised the Section held in Great Britain present this Scroll of Honour to . . . . . in order to commemorate his participation in the Joint Meeting organised by The American Institute of Mining and Metallurgical Engineers, The American Society for Metals, The Iron and Steel Institute, The Institute of Metals, Der Verein Deutscher Eisenhüttenleute, Die Deutsche Gesellschaft für Metallkunde, Le Centre National de Recherches Métallurgiques, La Société Française de Métallurgie and Jernkontoret.*"

The Seals of the Institutes are attached and the Scrolls are signed on behalf of The Iron and Steel Institute by Sir Charles Bruce-Gardner, Bt., President, Mr. William Barr, Honorary Treasurer, and Mr. K. Headlam-Morley, Secretary, and on behalf of The Institute of Metals by Dr. Maurice Cook, President, Mr. J. C. Colquhoun, Honorary Treasurer, and Lt.-Col. S. C. Guillan, Secretary.

Scrolls of Honour were awarded at the Opening Plenary Session in London on 1st June, 1955, to:

Members of the American Committee

James B. Austin (*Co-Chairman*)
Robert S. Archer
Howard Biers
John Chipman
William H. Eisenman
John J. Golden
Ernest O. Kirkendall (*Secretary*)
George A. Roberts
Clyde E. Williams

Members of the European Committee

Pierre Coheur
Eugène Dupuy
Sven Fornander
Kurt Thomas
Bernhard Trautmann

Other Office Bearers and Officials of the American Institute of Mining and Metallurgical Engineers and the American Society for Metals

Ray T. Bayless (*Editor of Transactions, A.S.M.*)
Louis R. Berner (*Former Chairman, Open-Hearth Steel Committee, A.I.M.E.*)
Walter Crafts (*Trustee, A.S.M.*)
Karl L. Fetters (*Trustee, A.S.M.*)
Francis B. Foley (*Past-President, A.S.M., and former Chairman of the Iron and Steel Division of A.I.M.E.*)
Frank P. Gilligan (*Past-President, A.S.M.*)
Herbert W. Graham (*Former Chairman of the Iron and Steel Division of A.I.M.E.*)
Walter E. Jominy (*Past-President, A.S.M.*)
John S. Marsh (*Former Chairman of the Iron and Steel Division of A.I.M.E.*)
William A. Pennington (*Treasurer, A.S.M.*)
Robert J. Raudebaugh (*Trustee, A.S.M.*)
Adolph O. Schaefer (*Vice-President, A.S.M.*)
Alvin H. Sommer (*Former Chairman of the Open-Hearth Steel Committee of A.I.M.E.*)
Bradley Stoughton (*Past-President, A.S.M.*)
E. E. Thum (*Editor of 'Metal Progress'*)
George M. Young (*Trustee, A.S.M.*)

Also to:

Edgar C. Bain (*Hatfield Memorial Lecturer*)
George S. Rose (*Secretary, American Iron and Steel Institute*)

Presidents of Co-operating European Societies

Paul Brenner (*Deutsche Gesellschaft für Metallkunde*)
Alfonso de Churruca y Calbeton (*Instituto del Hierro y del Acero*)
Aldo Daccò (*Associazione Italiana di Metallurgia*)
Josef Oberegger (*Eisenhütte Oesterreich*)
François Perot (*Centre National de Recherches Métallurgiques*)
Herman Schenck (*Verein deutscher Eisenhüttenleute*)
Joseph Marie Raoul de Vitry d'Avaucourt (*Société Française de Métallurgie*)
Evert Wijkander (*Jernkontoret*)

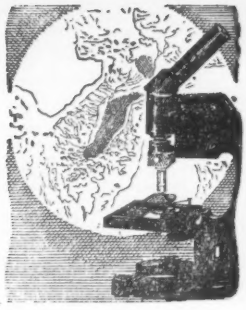
Other Representatives of Co-operating Continental Societies

Maurice de Courcel (*Société Française de Métallurgie*)
Alfred Decker (*Centre National de Recherches Métallurgiques*)
Karl Peter Harten (*Former Member of European Committee*)
Erich Loh (*Verein deutscher Eisenhtteünleute*)
Augustin Plana Sancho (*Instituto del Hierro y del Acero*)
Hans Schlacher (*Eisenhütte Oesterreich*)

At a later date, the Councils of The Iron and Steel Institute and of The Institute of Metals resolved that Scrolls of Honour should be awarded also to Lt.-Col. S. C. Guillan and Mr. K. Headlam-Morley.

PAPERS AND REPORTS ON
RESEARCH AND PRACTICE

Metallurgy · Plant Operation · Research



ANDREW CARNEGIE RESEARCH REPORT

The Effects of Sulphur, Selenium, and Tellurium on Graphite Formation in an Fe–C–Si Alloy

By S. Garber, B.Eng., Ph.D.

SYNOPSIS

The effects of melting temperature and cooling rate on graphite formation have been determined on iron–carbon–silicon alloys of hypo-eutectic and eutectic composition. The effects of the additions of sulphur, selenium, and tellurium on graphite formation in an alloy of hypo-eutectic composition have also been determined.

It is suggested that the changes of the graphite morphology induced in the iron–carbon–silicon alloy by the additions of sulphur or selenium are due to the modifications in the nucleation of the graphite and the growth rate of the 'eutectic' austenite. In the case of the tellurium additions, the results were not as reproducible as with the two other elements, probably because of the irregular losses of tellurium from the melt. 1076

Introduction

ALTHOUGH IT HAS LONG BEEN KNOWN that sulphur has an important influence on the properties of cast irons, the effect of this element on graphite formation was not observed until 1937. Boyles[1] then determined that iron–carbon–silicon alloys, which normally gave a fine undercooled type graphite, produced a coarser flake graphite when an addition of sulphur was made. He found that this element initially increased the size of the graphite and that further additions then resulted in a diminution.

LaPlanche,[2] using an experimental procedure similar to Boyles,[1] confirmed the effect of sulphur on graphite size. In both cases the sulphur was added to a high-purity hypo-eutectic Fe–C–Si alloy, melted in a nitrogen atmosphere, and reproducible cooling rates were maintained by cooling *in situ* in the furnace.

Using materials of still higher purity, Williams[3] demonstrated the powerful influence of sulphur on the mechanism of solidification of a binary Fe–C alloy of hypo-eutectic composition. The results showed that the effects of sulphur in a binary alloy were similar to those in the ternary ones used by LaPlanche[2] and Boyles.[1]

Whereas Boyles and LaPlanche interpreted this coarsening and refining of the graphite by sulphur in terms of a continuous increase in the stability of the carbide with increasing sulphur, Patterson[4] considered the formation of graphite in an impure Fe–C–Si alloy from the viewpoint of heterogeneous nucleation. On the evidence of microscopic examination and changes observed in the thermal critical points of eutectic crystallization, he suggested that the number of favourable foreign nuclei made available by additions to the melt determined the amount of undercooling and the type of graphite that was produced. The effect of sulphur additions, he stated, was to furnish particles of iron sulphide, the surfaces of which acted as two-dimensional nuclei for graphite and promoted its growth as flakes.

Keverian *et al.*[5] postulated that the interfacial energy between the graphite and the melt was the determining factor of graphite formation. The presence of surface-active elements such as sulphur or oxygen in the melts lowered the graphite/melt interfacial energy. Adding small percentages of elements such as cerium, magnesium, titanium, and zirconium neutralized these elements and increased the graphite/melt interfacial energy. The type of graphite produced depended on the degree of undercooling and the extent of the increase in interfacial energy.

In the molten Fe–C and Fe–C–Si alloys used in the above investigations sulphur had an appreciable

A report, received on 14th September, 1954, on a research carried out with the aid of a grant from the Andrew Carnegie Research Fund.

Dr. Garber was at Sheffield University when this work was carried out.

Table I

TERNARY HYPO-EUTECTIC BASE ALLOYS AND EUTECTIC ALLOY

Spectrographically, minor traces of other elements (Ni, 0·03%; Cu, 0·005%; Al, 0·01%) were the major impurities.
Ingots 14, 18, 21, and 24 were melted in a nitrogen atmosphere.
Ingot 25 was melted *in vacuo* at a pressure of 0·4 mm. Hg.

Ingot No.	C, %	Si, %	S, %	P, %	Mn, %	C.E.*
14	2·84	2·00	0·001	0·005	Nil	3·45
18	2·82	1·96	0·002			3·41
24	2·88	1·86	0·005			3·44
21	3·65	1·90	0·002			4·23
25	2·88	1·74	0·004			3·41

* C.E. %C + 0·33% Si (Schneidewind and McElwee[8]).

solubility, but the evidence indicated a very low solubility in the solid state. Boyles[1] noted that on solidification there was a segregation of sulphur to the eutectic cell boundaries. LaPlanche[2] also observed that there was a segregation of sulphides to the eutectic liquid. Kitchener[6] suggested that sulphur was almost completely insoluble in an Fe–C alloy in the solid state and he noted that it separated as brittle inclusions at the grain boundaries. There being no appreciable manganese present in these alloys, the sulphur was present as the iron monosulphide.

Sulphur, as a ' carbide stabilizer,' cannot be considered an alloying element in cast irons in the same sense as chromium, molybdenum, manganese, etc., whose atoms may act substitutionally in the carbide. A more definite determination of the role that small amounts of elements such as sulphur play in altering the mechanism of graphite formation should contribute to the further understanding of the mechanism itself.

Selenium and tellurium are in many respects akin to sulphur and, in view of the known effects of sulphur upon graphite formation, it was decided to make a comparative study of the effects of sulphur, selenium, and tellurium in alloys of high purity.

MATERIALS USED

All the alloys used in the investigation were made from oxidized Swedish iron, metallic silicon, and electrode graphite.

The iron contained less than 0·04% total impurities, excluding oxygen, which was present up to 0·2%. The metallic silicon was 99·8% pure and the electrode graphite had an ash content of 0·29%.

Five base alloys were made from these materials in a 35-kVA. high-frequency furnace and their compositions are given in Table I. Of these base alloys, 14, 18, 24, and 25 are of hypo-eutectic composition according to the section of the ternary equilibrium diagram after Greiner, Marsh, and Stoughton[7] for a constant silicon content of 2·0% ,and as calculated by the carbon equivalent formula of Schneidewind and McElwee.[8] Base alloy 21, according to this information, was of eutectic composition.

Further quaternary alloys were made in a similar manner and were subsequently used as master addition alloys to give the required amount of sulphur, selenium, or tellurium. The sulphur was added as

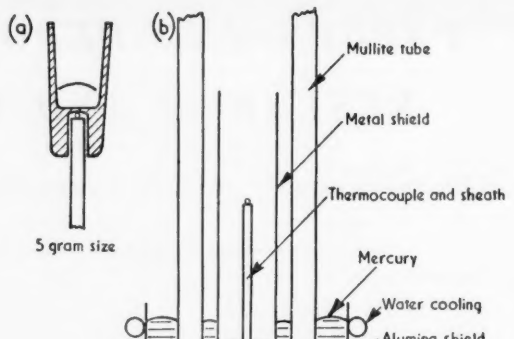


Fig. 1—(*a*) Alumina crucible; (*b*) mercury seal

roll sulphur, containing 0·05% ash, and the selenium and tellurium were added as metallic rod, both being 99·9% pure. Details of the composition of these addition alloys are in Table II.

The base and addition alloys were melted in a nitrogen atmosphere, with the exception of alloy 25, which was melted in a vacuum of 0·4 mm. Hg.

To minimize cracking, the crucibles in which the above alloys were melted were bonded with 3½% high-purity kaolin; they were lined with thoria in case the melting temperatures of the alloys became high enough for reduction of the alumina and clay by the carbon to occur.

For subsequent experiments 5-g. charges were melted in a specially constructed furnace. The crucibles for these charges, the design of which is illustrated in Fig. 1*a*, were made of 99·0% alumina. All the crucibles were produced by the slip-casting process.

EXPERIMENTAL PROCEDURE

Before studying the effects of the addition elements, it was desired to establish the effects of cooling rate and melting temperature on the graphite formation

Table II

QUATERNARY ADDITION ALLOYS

All ingots melted under nitrogen

Ingot No.	C, %	Si, %	S, %	Se, %	Te, %
16	2·76	1·92	0·413		
19	2·84	1·93	1·94		
20	2·82	1·97		0·55	
28	2·87	2·10		0·69	
22	2·86	1·88			0·81
26	2·92	1·81			0·68

in the pure Fe–C–Si base alloys. For this purpose a furnace was constructed that would provide a wide range of cooling rates.

The crucible containing the 5-g. charge could be moved into the hot zone for a given period and then, in less than a second, be withdrawn to a cooler region of the furnace tube. During this operation the sample was continuously under a nitrogen atmosphere. This was made possible by the use of an adaptation of the Wilson seal in conjunction with a mercury seal, which allowed a water-cooled refractory pedestal to move the crucible up or down in the furnace tube (Fig. 1*b*). The cooling rate was dependent on the temperature of the zone of the furnace tube to which the crucible was withdrawn.

Where an extremely fast cooling rate was desired, the pedestal arrangement was removed and a flask containing the iced brine was attached to the mercury seal at the bottom of the tube. The crucible, held in a platinum cradle, was introduced through the top of the furnace and was suspended from a stainless-steel wire attached to a cotton thread. By cutting the thread, the crucible and cradle dropped immediately into the quenching bath. The small crucibles used for this work did not have the heavy-section alumina base as shown in Fig. 1*a*.

Since the design of the furnace did not permit it to be evacuated, the system was flushed with nitrogen for at least an hour before the charge was moved into the melting zone, and the flow of gas was maintained during the melting and cooling cycles.

According to the suppliers, the commercial nitrogen used throughout this work had an analysis of 99·9% nitrogen, on the dry gas. The impurities were: oxygen showing less than 10 v.p.m.; carbon dioxide, up to 20 v.p.m.; carbon monoxide, nil; other carbon compounds as carbon dioxide, less than 5 v.p.m.; hydrogen, nil; neon, approximately 0·1% (variable); helium, 0·03% (variable); and argon, probably less than 50 v.p.m. Before it entered the furnace, the nitrogen was passed through a silica-gel tower and then over a series of boats containing phosphorus pentoxide. The furnace atmosphere was maintained at a positive pressure of $\frac{1}{4}$ in. Hg and $\frac{3}{4}$ in. W.G.

A Pt/Pt–13% Rh thermocouple in conjunction with a millivolt potentiometer was used for measuring the temperature near the melting zone in the tube. A similar thermocouple which entered through the bottom of the furnace measured the temperature of the crucible.

The aluminous porcelain sheath protecting the second thermocouple acted as the extension to the pedestal and as the seat for the crucible (Figs. 1*a* and *b*).

A Kent recorder was used for determining the slow rates of cooling. For faster rates the leads of the crucible couple were connected to a horizontal milliammeter. From the start of cooling, milliammeter readings were recorded every 5 sec. by a ciné camera. The ammeter had been calibrated previously against the potentiometer over a temperature range of 1425–200° C. and an appropriate conversion curve obtained. From the film, the milliamperes *v.* time readings were obtained and the cooling curve plotted.

Figure 2 shows typical cooling curves that were obtained with the fastest rate of furnace cooling, for

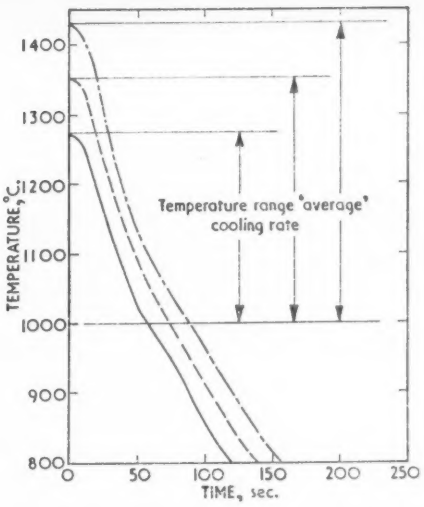


Fig. 2—Cooling curves: addition series

melting temperatures of 1275°, 1350°, and 1425° C. For the purpose of comparing the cooling rates of the crucible from any of the melting temperatures, an 'average' cooling rate was used as the basis for comparison. This was determined by dividing the temperature drop from the melting temperature to 1000° C. by the time.

For those ingots that were brine-quenched the 'average' cooling rate was approximated by observing the time from quenching until the red glow of the crucible and sample disappeared. The temperature at the latter point was assumed to be 700° C.

RESULTS OF COOLING EXPERIMENTS

In these preliminary experiments, the effects of cooling rates on the graphite formation of the hypo-eutectic base alloy (14 and 18, Table I) were determined for three melting temperatures, 1275°, 1350°, and 1425° C., and for the eutectic composition base alloy (21) at 1200°, 1275°, and 1350° C.

Hypo-Eutectic Alloy

Cooling rates of ~ 115 to ~ 145 C. deg./sec. were obtained by quenching into iced brine from the three melting temperatures. Clusters of small graphite nodules were detected in the white iron matrix of the ingot quenched from 1275° C. (Fig. 4*a*). The number of small graphite particles found in the quenched structure decreased when the melting temperature of the alloy was increased. In the ingot quenched from 1425° C., a few suspected graphite particles were observed but they were too small to be properly identified.

From a melting temperature of 1275° C., the cooling rates obtained in the various zones of the furnace tube ranged from 270 to 40 C. deg./min. With the fastest rate of cooling, the structure showed a predominantly undercooled and fine flake graphite (Fig. 4*b*). By decreasing the cooling rate, there was a progressive

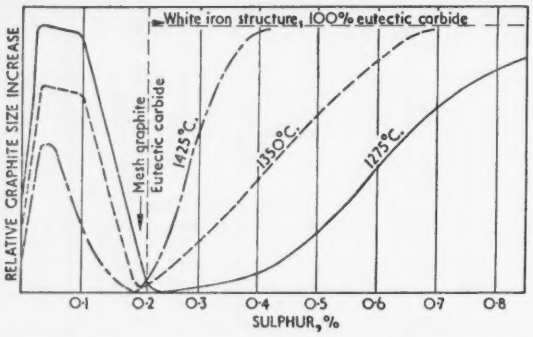


Fig. 3—Schematic representation of sulphur effects

coarsening of the graphite until, at the slowest rate, the graphite was in the form of relatively coarse flakes (Fig. 4*c*). In the ingots melted at 1350° C. and cooled with rates of 280 to 24 C. deg./min., the change in the graphite was similar to that observed in the 1275° C. melted structures, but the increase in graphite size was not as great. However, a change of the cooling rate from 320 to 45 C. deg./min., from the melting temperature of 1425° C., produced very little change in the graphite (Figs. 5*a* and *b*).

Eutectic Alloy

In the original base alloy, ingot 21 (Table I), the predominant graphite form was normal undercooled with fine flakes at the eutectic cell boundaries (Fig. 6). There was no primary graphite present. Small original austenite dendrites were distributed throughout the structure indicating that the apparent cooling path of the ternary alloy was slightly to the hypo-eutectic side of the eutectic trough.

All the 5-g. ingots quenched into iced brine from the four temperatures 1200°, 1275°, 1350°, and 1425° C. showed zones of structure in which there were considerable amounts of graphite. The cooling rates were estimated as ranging from ~ 85 to ~ 145 C. deg./sec. The amount of graphite present decreased with an increased melting temperature, the graphite being replaced by eutectic carbide. In the samples melted at the two lower temperatures, most of the graphite consisted of nodules and a fine globular undercooled type (Fig. 7*a*). In the structure of the quenched ingot, melted at 1350° C., the nodules had almost disappeared and in the ingot that had been melted at 1425° C. the graphite was mainly the fine globular undercooled kind.

In the structures of all the specimens cooled in the furnace zones, primary graphite of nodular and flake-aggregate form were observed. The size and number of these graphite particles decreased with increased melting temperatures; the size increased, however, with a decrease in the cooling rate for a given melting temperature.

The cooling rate was varied from 215 to 25 C. deg./min. in the 1200° C. melting temperature series; for the 1275° C. series, from 250 to 31 C. deg./min.; for the 1350° C. series from 275 to 27 C. deg./min.

The eutectic graphite in the ingot obtained with the fastest cooling rate from 1200° C. was predominantly flake with small areas of the undercooled type. Figure 7*b* shows the boundary of a small undercooled zone (note the small graphite nodules) and a flake zone (note the flake-aggregate graphite). Decreasing the cooling rate from this melting temperature decreased the amount of undercooled and increased the amount and size of the flake graphite. In the ingots that had been melted at 1275° C., the graphite structures were similar to those obtained with the lower melting temperature except that there was less flake and more undercooled graphite. This refinement of the graphite with an increased melting temperature became very apparent with a temperature of 1350° C., when the graphite in the fastest furnace-cooled specimen was found to be predominantly of the undercooled type. The coarsening of the graphite with decreased cooling rates from this temperature was not so marked as with the two lower melting temperatures.

EFFECTS OF ADDITION ELEMENTS

The graphite structures obtained in the 5-g. ingots of the hypo-eutectic alloy when cooled in the lowest zone of the furnace tube (that is, at the fastest rate possible in the furnace) consisted predominantly of A.S.T.M. Type *D* undercooled graphite, with small graphite flakes extending from the undercooled pools. The slight variations in the cooling rate (from a constant melting temperature) obtained when cooling the crucible in this zone produced very little change in the graphite structure. Because of this reproducibility of the graphite structure and since a fine graphite structure would be most favourable for detecting changes in the graphite size, this method of cooling was adopted as the standard one for the determination of the effects of the addition elements. The typical cooling curves of the crucible obtained under these conditions have already been indicated in Fig. 2.

The experimental conditions were the same as those used in the preliminary work. The 5-g. charge consisting of the mixture of hypo-eutectic base alloy and master addition alloy was held in the cold zone of the furnace tube whilst the furnace was flushed with nitrogen; then the crucible and contents were moved into the melting zone for 15 min., after which they were withdrawn and allowed to cool. Similarly, the effects of the addition elements were determined for three melting temperatures, viz. 1275°, 1350°, and 1425° C.

The 5-g. ingots were sectioned vertically through the centre and one half was mounted for microscopic examination; the other half was retained for chemical analysis. Polarized light was used to confirm the identification of the inclusions and, where necessary, the graphite.

Effects of Sulphur Additions

A schematic representation of the changes in the graphite formation with increasing sulphur additions is presented in Fig. 3.

The structure of the 1275° C. remelted base alloy containing 0·002% sulphur was similar to Fig. 4*b* and consisted of normal undercooled graphite with a small amount of fine flake. In the alloys melted at the same temperature it was found that with increasing sulphur, the flake graphite increased in amount and size with a corresponding decrease in the amount of undercooled graphite, until with a sulphur content of 0·028%, the

(a) Iced-brine quench
Cooling rate ~ 115° C./sec.
Etched picral × 600

(b) Furnace-cooled
Cooling rate 270° C./min.
Unetched × 100

(c) Furnace-cooled
Cooling rate 40° C./min. × 100

Fig. 4—Hypo-eutectic alloy at 1275 C.

(a) Cooling rate 320° C./min.

(b) Cooling rate 45° C./min.

Fig. 5—Hypo-eutectic alloy at 1425 C.; furnace-cooled; unetched × 100

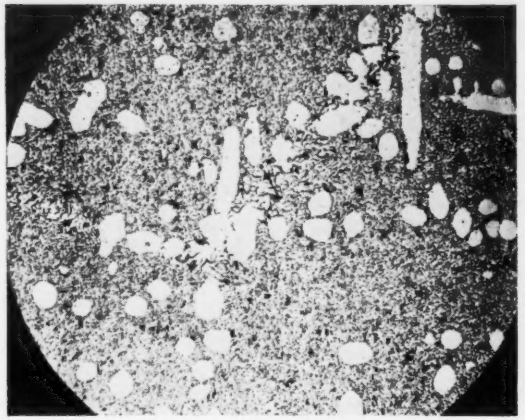
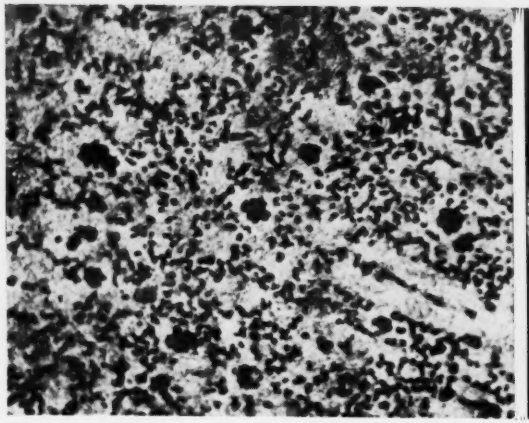
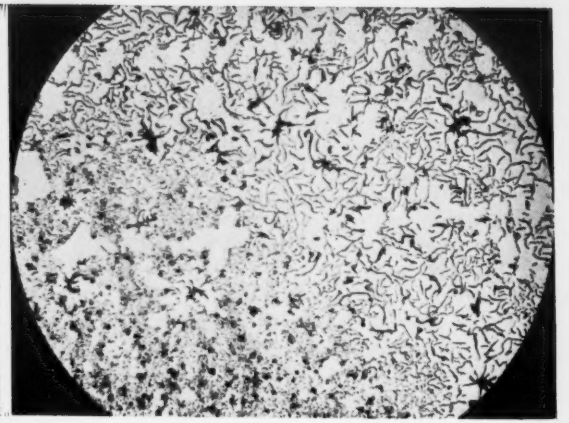


Fig. 6—No. 21 ingot, eutectic alloy; unetched × 100

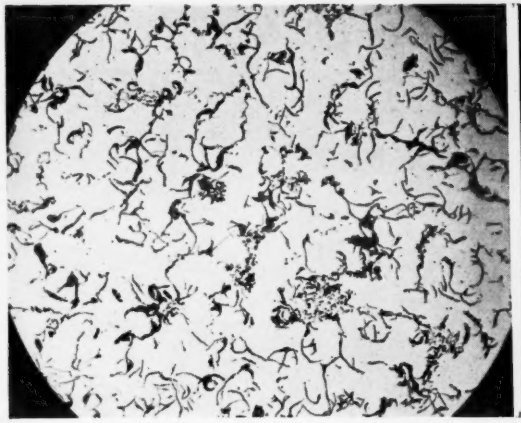


(*a*) Iced-brine quench
Cooling rate ~ 85° C./sec.
Etched picral
× 600

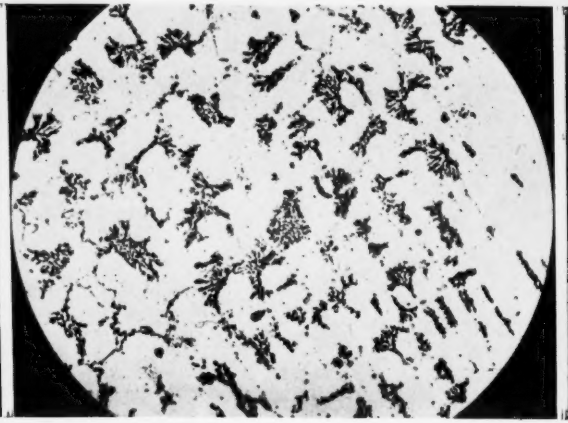


(*b*) Furnace-cooled
Cooling rate 215° C./min.
Unetched
× 100

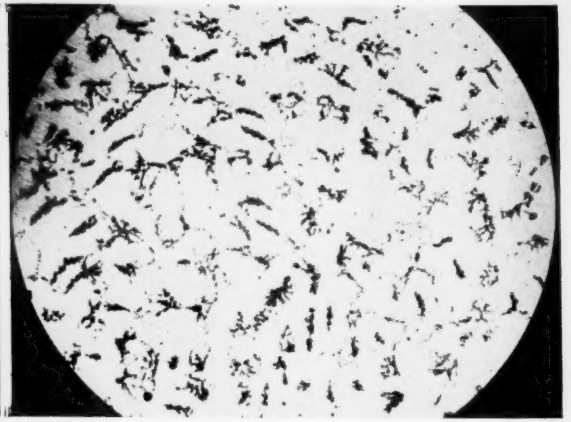
Fig. 7—Eutectic alloy at 1200° C.



(*a*) 0·028% S



(*b*) 0·22% S



(*c*) 0·45% S

Fig. 8—Effect of increasing sulphur content; 1275° C., unetched × 100

(*a*) No addition (*b*) 0·042% S (*c*) 0·20% S

Fig. 9—Effect of increasing sulphur content; hypo-eutectic alloy, 1350° C.; etched picral × 600

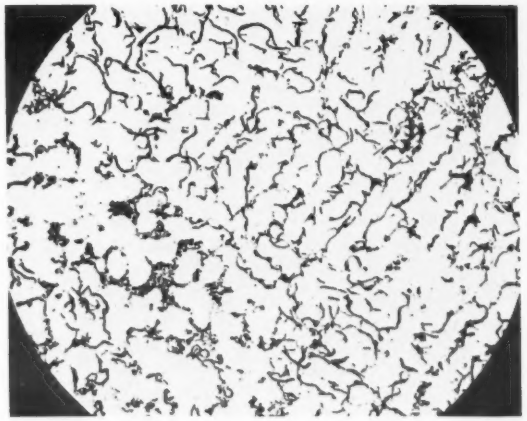
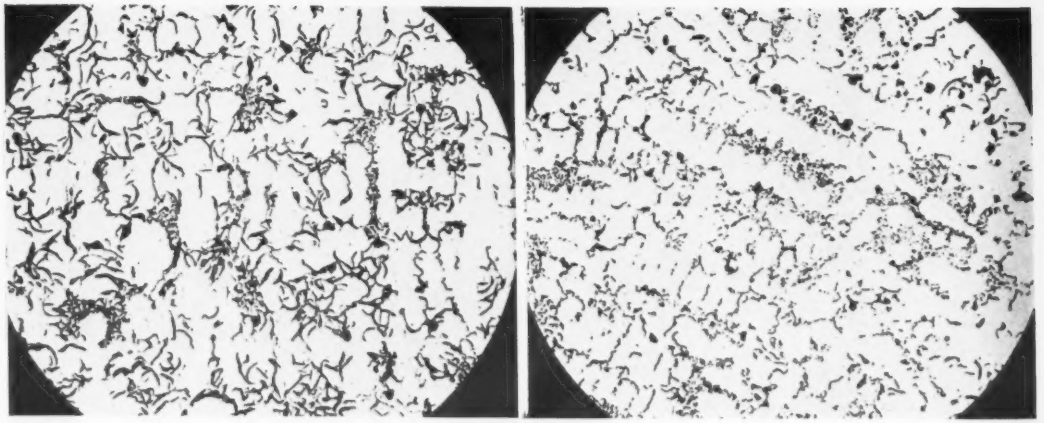


Fig. 10—0·023% S at 1425° C., unetched × 100

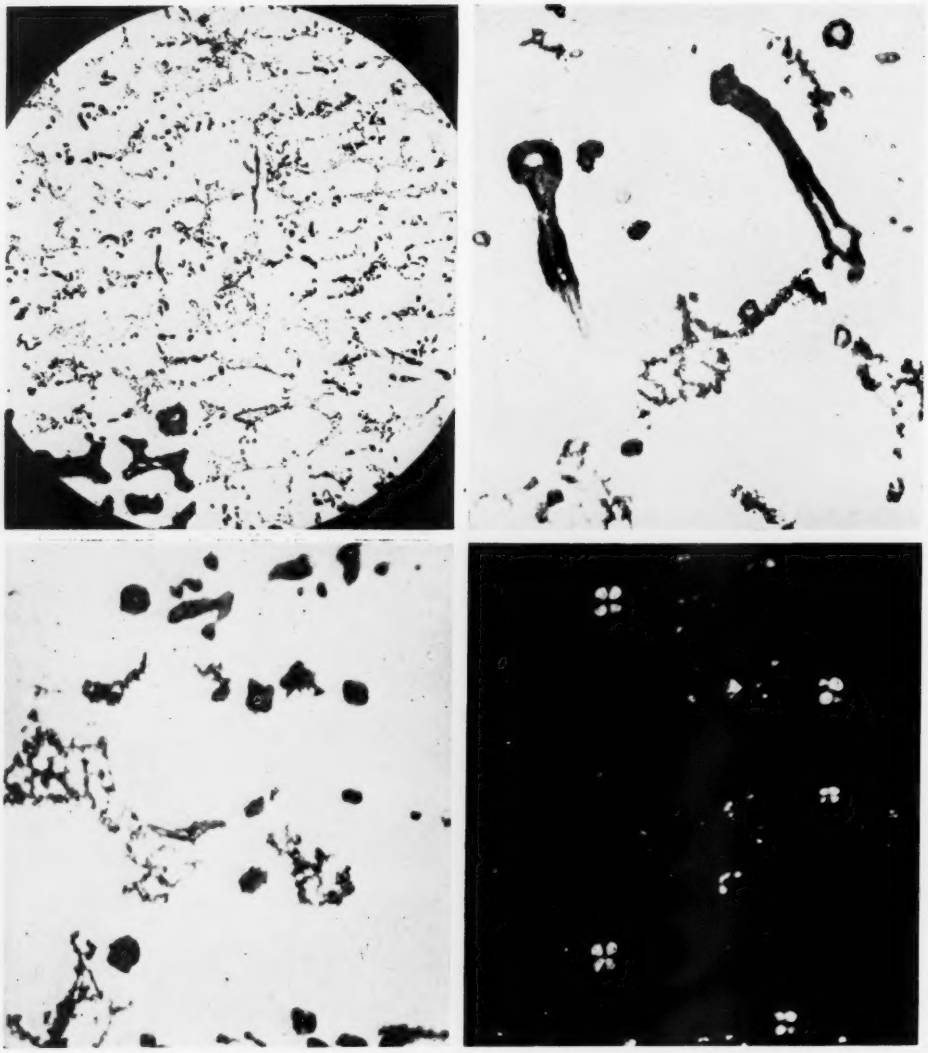


(*a*) 1275° C. (*b*) 1425° C.

Fig. 11—Addition of 0·005% Se, unetched × 100

(*a*) × 100

(*b*) × 600



(*c*) × 600; ordinary illumination

(*d*) × 600; same field as (*c*), between crossed polaroids

Fig. 12—Addition of 0·20% Se, 1350° C., unetched

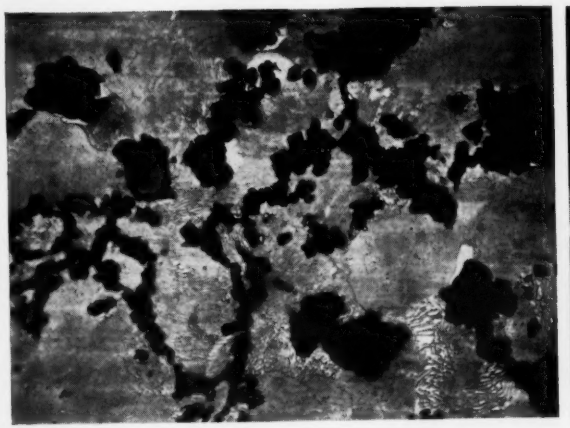
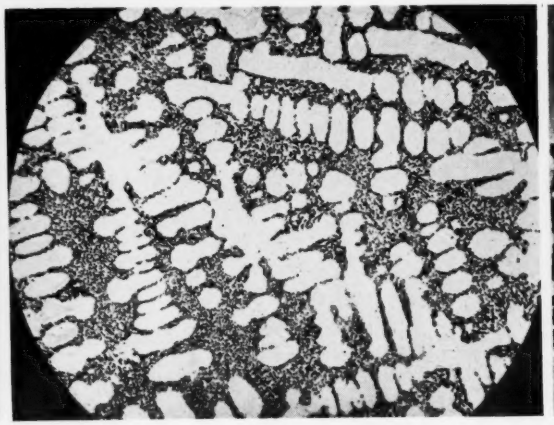
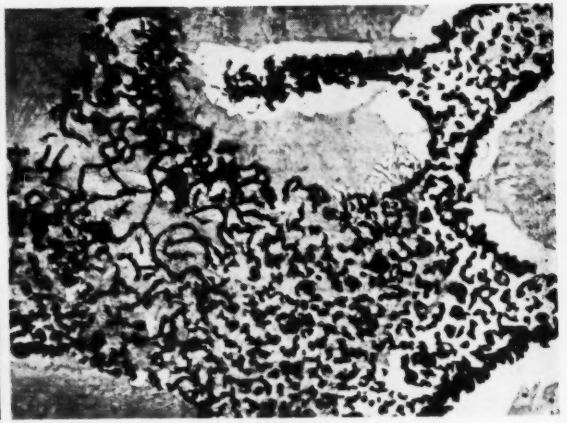


Fig. 13—Addition of 0·55% Se, 1275° C., etched picral × 600

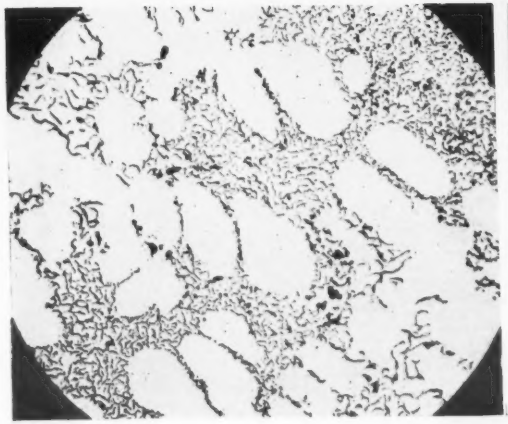


(a) 0·005% Te added
Unetched
× 100



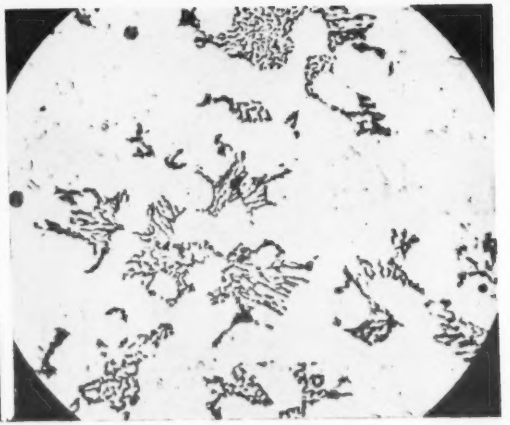
(b) 0·01% Te added
Etched picral
× 600

Fig. 14—Effect of tellurium additions at 1275° C.



(a) No addition

(b) 0·025% S added



(c) 0·175% S added

Fig. 15—Effect of sulphur additions; 1350° C., unetched × 100

[Garber

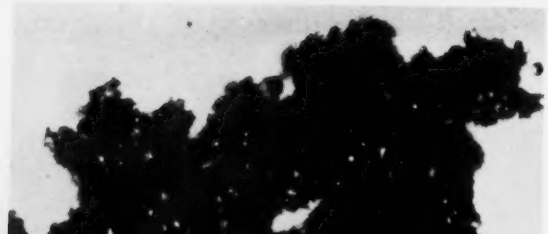


Fig. 16—Black powder × 35

(*a*) Ordinary illumination (*b*) Plane polarized light

Fig. 17—Iron monoselenide, No. 20 ingot, unetched × 750

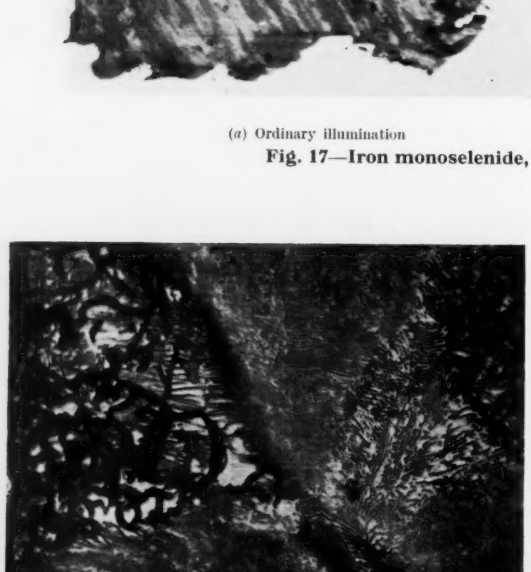


Fig. 18—Hypo-eutectic alloy, No. 24 ingot, showing sulphide inclusions. Etched picral × 600

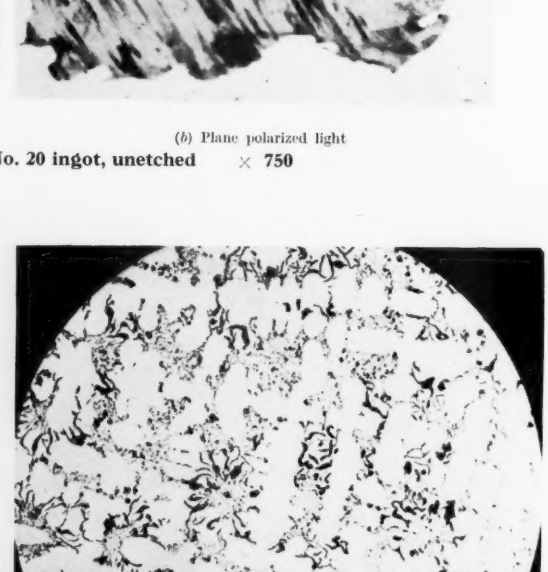


Fig. 19—Rosette graphite in alloy with 0·002% S at 1275° C. Unetched × 100

predominant feature was a relatively coarse flake graphite (Fig. 8*a*). This relatively coarse flake persisted as the predominant form of graphite with sulphur as high as ~ 0·1%. Between 0·028 and ~ 0·1% sulphur the size of the flakes remained fairly constant.

With 0·04% S, a few pools of mesh-type undercooled graphite (previously observed by Morrogh and Williams[9]) began to appear. At 0·22% S the flake graphite had been completely replaced with this mesh graphite (Fig. 8*b*). Concurrent with the appearance of this type of graphite was the appearance of isolated small graphite spherulites. Further sulphur additions changed the interdendritic mesh graphite into compact aggregates (Fig. 8*c*). With further sulphur increases, this structure was in turn replaced by the carbide eutectic in increasing amounts until it became the major phase of the eutectic carbon.

With melting temperatures of 1350° and 1425° C. the effects of the sulphur additions were similar to those observed when using the lowest melting temperature. As the amount of sulphur increased, in the 1350° C. series, the graphite changed from a predominantly normal undercooled and small flake graphite to a coarser flake graphite, until the normal undercooled structure had practically disappeared at 0·026% S.

From 0·026% to ~ 0·1% S, there was no change in the size of the graphite flake, but a small quantity of mesh began to appear. With 0·20% S, an almost fully mesh structure was obtained. Figures 9*a–c*, show at higher magnification the change from predominantly normal undercooled to flake and then to mesh graphite. Further increases in the sulphur content were accompanied by the appearance of the eutectic carbide, and at 0·6% it was the predominant interdendritic phase.

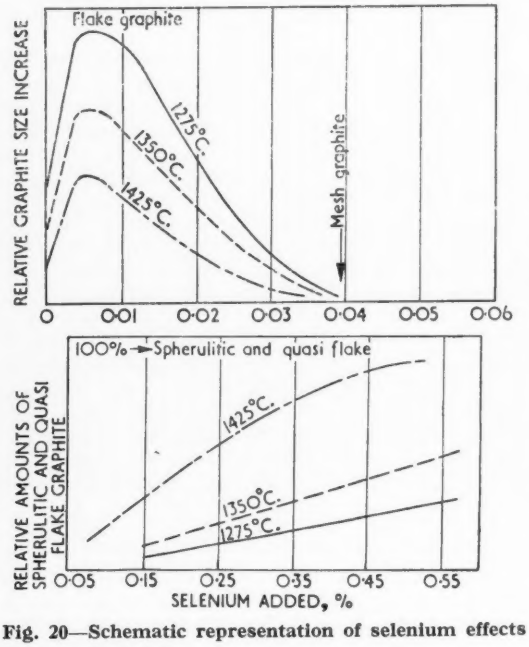


Fig. 20—Schematic representation of selenium effects

In the 1425° C. melting temperature series, the sulphur additions had a coarsening effect on the graphite, which reached a maximum in size and amount between 0·023% (Fig. 10) and 0·039% S. The graphite did not become wholly flake over this range. At the lower-sulphur end an estimated 20% of the interdendritic graphite was the normal undercooled variety and at the higher sulphur content about the same amount of mesh graphite existed. With 0·09% S, the mesh type formed more than half, and small flakes the balance, of the graphite and with 0·187% S, the graphite was almost completely mesh type. As with the other two melting temperatures, the amount of eutectic carbide then increased with increasing sulphur additions.

The structures obtained with the three melting temperatures were fundamentally the same. The variations found were as follows:

(i) The normal undercooled and small flake graphite structure obtained by remelting the pure base alloy became finer the higher the melting temperature

(ii) The size of the original austenite dendrites became smaller the higher the melting temperature

(iii) The graphite flakes produced by the additions of sulphur were smaller with increased melting temperatures (Figs. 8*a* and 10)

(iv) The higher the melting temperature, the smaller were the additions of sulphur required to obtain a predominantly white iron structure.

In the 1275° and 1350° C. series, at 0·04% S addition, a sooty substance was found on the surface of the ingots, the amount of which increased with increasing sulphur additions. For the 1425° C. series this black powder was not formed until the sulphur had reached 0·29% and then it did not appear in as large amounts as at the lower temperatures.

Effects of Selenium

Examination under polarized light showed that the inclusions obtained by the addition of selenium to an Fe–C–Si alloy were anisotropic and exhibited strong reflection pleochroism. This indicated that the selenide formed was probably the iron monoselenide.

A schematic representation of the changes in the graphite formation with increasing selenium additions is shown in Fig. 20.

For the three melting temperature series, the results were analogous to those obtained with the sulphur. With a 1275° C. melting temperature, the graphite coarsened up to 0·01% Se addition (inclusive), and was then refined, being completely mesh at 0·04% Se addition. Similarly, with the other two melting temperatures an initial coarsening and then refining of the graphite occurred. The amount and size of the flakes produced by the selenium additions decreased with an increased melting temperature. Figures 11*a* and *b* show the maximum size flake structure for the 1275° and 1425° C. melting series respectively. During the coarsening of the graphite by the selenium, the flakes did not reach the maximum size obtained with the sulphur and the coarsening did not persist over as wide a range of additions.

In the sulphur series, after enough of that element had been added to bring about a refinement in the graphite (mesh graphite), further additions resulted in the appearance of eutectic carbide, which increased

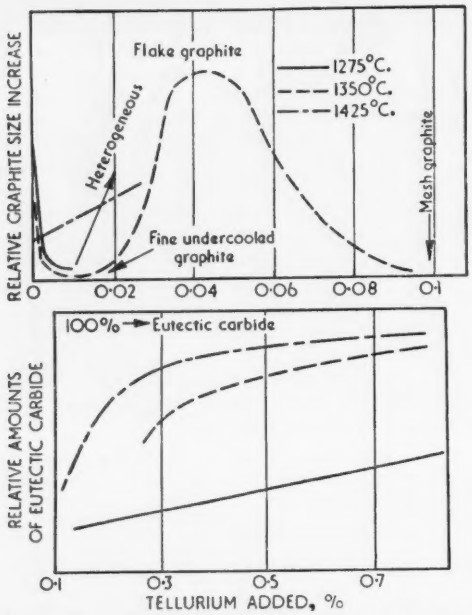


Fig. 21—Schematic representation of tellurium effects

in amount as the percentage of sulphur was further increased. With selenium, however, after a similar coarsening and refinement of the graphite had occurred, further additions resulted in the appearance and continued increase of a globular and quasi-flake type graphite. Figures 12*a* and *b* show this type of structure. This globular type of graphite, associated with the quasi-flakes, proved to be small spherulites. They showed the ' maltese cross ' pattern between crossed polaroids (Figs. 12*c* and *d*). For given additions, the increases in the amount of this ' post-mesh ' structure were greater, the higher the melting temperature.

At the lowest melting temperature, with the additions of 0·20% selenium and over, besides the mesh and the globular and quasi-flake types of graphite, there also appeared a third type—a nodular structure with an irregular outline, which was very difficult to polish. This latter type proved to be ' agglomerates ' of graphite and iron selenide (Fig. 13). It was also observed in the 1350° C. series at the maximum addition, but this structure was not present in the ingots melted at 1425° C.

The black powder began to appear on the surface of the ingots melted at 1275° C. with 0·002% selenium addition, but was not present in very noticeable quantities until 0·01% had been added. With a melting temperature of 1350° C., it was definitely observed with 0·01% Se, and with 0·04% Se addition with a melting temperature of 1425° C. With increasing additions over these amounts, the sooty material increased in quantity.

Effects of Tellurium

In contrast to sulphur and selenium, tellurium for the two lower melting temperatures at first showed a refining of the graphite (Figs. 14*a* and *b*) with additions of up to 0·01% Te inclusive. In the 1425° C. series this refinement was not observed; there was a slight increase in the size of the graphite.

With the lowest melting temperature, additions of over 0·01% tellurium produced very heterogeneous and porous ingots. Zones of flake, normal undercooled, and mesh graphite structures were observed together with eutectic carbide; the latter phase increased with increased additions, whereas the flake and normal undercooled graphite disappeared.

The structures of the ingots when a melting temperature of 1350° C. was used were more uniform than at the lower melting temperature. After the initial refining there was a coarsening of the graphite, then a refinement, with a fully mesh type graphite being obtained. Further additions then produced eutectic carbide. Most of these melts were repeated at least twice and the results were reproducible except for two ingots. They were the 0·01% and 0·04% Te addition alloys. The former alloy had a mottled structure and the latter alloy gave a predominantly grey structure with the graphite almost completely spherulitic. The repeats of these alloys gave a refined undercooled and a flake structure, respectively.

Using a melting temperature of 1425° C., with successive additions of tellurium from 0·002 to 0·01%, resulted in a slight coarsening of the graphite. The changes in the graphite structure with the additions between 0·01% and 0·20% were inconsistent. A mesh, a flake and undercooled, and a predominantly spherulitic graphite structure were obtained in that order with increasing additions. At 0·20% addition and over the structure was predominantly carbidic.

With the lowest melting temperature, the graphite changes are only presented graphically up to 0·01% addition (Fig. 21). The heterogeneous structures obtained with higher additions made it impossible to portray the changes schematically. The 1350° C. curve indicates the refinement with the lower additions, then the coarsening and subsequent refining of the graphite.

Because of the inconsistent changes in the graphite structure with the additions between 0·01% and 0·20%, at 1425° C., only the slight coarsening with the small additions has been indicated in the graphite curve.

In these series the amount of the black powder was observed to be greater than with the sulphur and selenium. With a melting temperature of 1275° C. the black substance first appeared with the smallest addition of 0·002% and with 0·04% there was sufficient to cover the top of the ingot completely. With a melting temperature of 1350° C., a few black specks were seen on the ingots with the addition of 0·002% Te, and with 0·04% the sooty substance again almost completely covered the ingot. With a melting temperature of 1425° C., however, this black material did not appear until an addition of 0·03% had been made. With any melting temperature, the black substance increased in amount with increased additions.

Note on the Analysis of the Addition Elements

Accurate gravimetric analyses of the sulphur, selenium, or tellurium were obtained on the master addition alloys. With the 5-g. ingots produced during

the addition series, only one half of the ingot was available for analysis and in certain instances the amount available was about 1 g. only. Therefore the analysis of sulphur was done by the combustion method on ingots that had up to 0·1% of that element added to the charge. Over this amount, the gravimetric estimation was used. The percentages obtained by analysis were of the same order of magnitude as the nominal additions and the figures given in the text as the amounts of ' sulphur added ' are the actual analyses of the ingots. The exceptions are where there was not sufficient sample available and these amounts are the nominal additions and are prefixed with the ' approximate ' symbol (~).

The ternary base alloys were analysed for sulphur by the combustion method.

Because of the small amounts of selenium and tellurium involved at the lower range of additions and also the size of the samples, the colorimetric method of analysis for these elements was attempted. The difficulty of holding the elements in a colloidal suspension made it impossible to obtain satisfactory estimations of the actual values of the amounts retained in the small melts.

Some of these samples in which the graphite structure had undergone a marked change were micro-analysed. The results indicated that in the case of tellurium there was a relatively high loss of that element from the melt, at the two higher melting temperatures. None of the ingots melted at the lower temperature were analysed, because of their marked heterogeneous character above 0·01% Te addition.

The loss of tellurium appeared to be inconsistent and the erratic behaviour of this element in its effects on the graphite formation can be attributed in part to the varying amounts that are retained in the melts.

Since the amount of black powder that appeared on the surface of the ingots appeared to vary directly with the amount of tellurium added to the charge, the removal of this graphite from the melt was a function of the original amount of the addition.

In the case of the selenium additions, there appeared to be a slight loss of this element from the melts, which did not seriously affect the reproducibility and consistency of the graphite formation changes. The loss was greatest with the highest melting temperature.

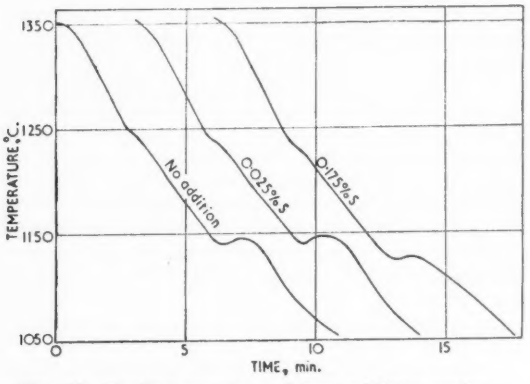


Fig. 22—Cooling curves: sulphur addition series

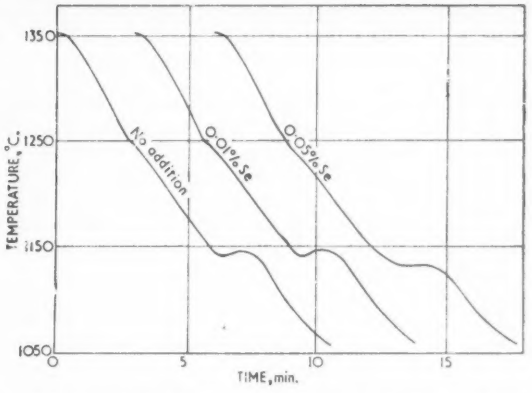


Fig. 23—Cooling curves: selenium addition series

Since satisfactory comprehensive series of analyses of these elements were not obtained, the figures quoted as ' amounts of selenium (or tellurium) added ' are based on the weight of the quaternary addition alloy in the 5-g. charge and the accurate analysis of the said selenium (or tellurium) master alloy.

Cooling Curves

A series of cooling curves were taken to determine what changes sulphur and selenium additions would make to the thermal arrests. No curves were taken with the tellurium owing to the inconsistent results of this element.

The heating apparatus used was a radio-frequency furnace. The alumina crucible containing the 10-g. charge was positioned inside a graphite crucible, which acted as the heating medium. To keep the charge under a nitrogen atmosphere, the crucibles were contained in a silica tube around which the heating coil was wound. Control of the power output was achieved by controlling the current to the primary coil of the transformer that supplied the rectifiers feeding the valve. A Pt/Pt–13% Rh thermocouple encased in a $\frac{1}{8}$-in. o.d. silica sheath was used for recording the temperature. The hot junction was placed in a similar position in each melt and the melting temperature used was 1350 ± 5° C. Reproducible cooling was obtained by reducing the power input to the heating coil to the same amount for each cooling cycle.

This cooling rate was such that the pure ternary alloy solidified with a predominantly undercooled-type graphite structure. Charges were then melted containing sufficient sulphur or selenium to produce maximum flake size and also a fully mesh-type graphite. These values were taken from the results of the 5-g. addition series. They were 0·025% S and 0·01% Se additions to produce flake graphite and 0·175% S and 0·05% Se additions for the mesh type.

Figure 22 shows the three curves obtained for the sulphur additions. As expected, the graphite structures obtained were an undercooled, a relatively coarse flake, and a mesh structure, respectively (Figs. 15*a–c*).

The curves showed that with an addition of 0·025% sulphur, the temperature range of the solidification of the eutectic hardly altered, but there appeared to

be a slight increase in the time over which solidification occurred. With 0·175% S addition, the changes in curvature, indicating eutectic solidification, occurred at a lower temperature range, and the curvature changes are not as abrupt as in the other two curves.

The cooling curves for the selenium series (Fig. 23) are similar to those obtained with the sulphur additions. The graphite structures obtained were also similar, except that the flakes were not as coarse as those produced by the sulphur, and the predominantly mesh structure showed small amounts of the globular and quasi-flake type graphite. With 0·01% Se there was no obvious change in the thermal arrest, but with the 0·05% Se addition the eutectic solidification took place over a lower temperature range and a longer time. However, this temperature range was not as low as that obtained with the 0·175% S addition.

From the curves it would appear that at the stage where the graphite and eutectic austenite are precipitated there were no major differences in the solidification processes that produced the fine undercooled and the flake graphite.

The ingots with the higher sulphur and selenium additions were covered with a thin layer of the fine sooty powder. Their cooling curves suggested that the mesh-type structures obtained with these additions were the product of a solidification that occurred at a lower temperature range than those which produced the other two forms of graphite. From the shapes of the curves it appeared that the solidification rate was faster with the higher sulphur addition than with the selenium one but that with the sulphur, solidification occurred at a lower temperature range.

Identification of the Black Powder

Under the microscope this black powder, which was extremely light in weight, appeared to be an agglomeration of small globular particles and graphite (Fig. 16). It reacted as a ferromagnetic substance and this was attributed to the very small metallic particles to which the graphite appeared to stick.

Spot tests[10] did not give a positive reaction for any of the three addition elements when the respective samples were tested.

X-ray diffraction pictures were taken, using CoK_α radiation. A 9-cm. camera was used and the specimens were rolled into ½-mm dia. rods, with gum tragacanth as a binder.

The results confirmed that graphite and iron were definitely present in this black substance and that there were no other compounds or elements present in sufficient quantities for their lines to be obtained. Though this black substance consisted mainly of carbon as graphite, analyses showed that there was very little loss of carbon in the ingots.

Levy[11] observed a magnetic sooty material above the immiscible sulphide-rich layer on his Fe–C–S ingots. However, this powder contained a high percentage of sulphur and Levy said it was probably an ' oxy-sulphide.' Reference was also made in the same paper to work by Smith and Weston in which cast iron and sulphide were melted in closed crucibles and a sooty deposit was obtained.

Patterson[4] observed that after 0·35% sulphur was added to an impure Fe–C–Si alloy, a soot-like graphite layer was found on the ingot and between the ingot and the crucible wall.

When the quaternary master addition alloys were made, there was none of this material to be found on the ingots. When they were remelted at temperatures up to 1425° C. they invariably produced the black powder. Considered with the fact that when equal quantities of addition alloys were added to a base alloy, less powder was observed on those ingots melted at the higher temperatures, it must be concluded that the appearance of the graphite-rich powder was dependent on temperature.

Visual observations of the 5-g. melts through the Pyrex window at the top of the furnace indicated that this black powder was formed during the melting and not the freezing of the alloy.

Note on the Distribution of the Inclusions

From the colour and the polarized light identifications, it was established that the addition elements were present as iron monosulphide, selenide, or telluride, respectively, in the master alloys. The three types of inclusions have a crystal lattice of the nickel-arsenide-type hexagonal structure, and they gave the typical anisotropic reaction by becoming light and dark four times in a 360° rotation between crossed polaroids.

In reflected light the iron sulphide was khaki-coloured; the telluride was light grey, and under plane polarized light exhibited reflection pleochroism, the colour varying from dark grey to light tan. Under ordinary illumination, the selenide appeared to vary in colour from light to medium grey. Since many of the selenides were polycrystalline, these shades of grey were visible within the same inclusion (Fig. 17*a*). This effect was due to the partially plane-polarized light of the ordinary illumination and to the fact that the colour of the selenide depended on its orientation with respect to the plane of polarization. This was more obvious when the inclusion was viewed under fully plane-polarized light (Fig. 17*b*).

In the hypo-eutectic base alloys, even at the low sulphur contents in the original ingots (0·001–0·005% S), very small sulphide inclusions were segregated to the eutectic cell boundaries (Fig. 18). Similar inclusions were also observed in the furnace-cooled 5-g. remelts of these alloys.

With increasing sulphur additions, the number of these small khaki-coloured inclusions increased and they usually occurred as clusters in the interdendritic areas.

With the selenium additions, it was not until sufficient had been added to produce the mesh or post-mesh structures that any of the inclusions could be definitely identified, by their colour or behaviour under polarized light, as selenides. When they did appear they were interdendritically segregated. With the additions of up to 0·04% Se there appeared to be a slight increase in the number of small khaki-coloured inclusions, which could not be identified as anything but sulphides.

Similarly, with the tellurium additions, although the small khaki-coloured inclusions appeared to increase with the first additions, no tellurides were identified until the larger additions had been made.

At the higher additions of the three elements massive inclusions were observed. The sulphides and selenides were globular, whereas the tellurides were found to fill the interdendritic spaces. These large inclusions indicated that the amount of the addition element had exceeded its solubility in the molten state, and that there is probably an immiscibility gap in the Fe–C–Si–S and Fe–C–Si–Se systems similar to that existing in the Fe–C–S system.

DISCUSSION

Melting Temperature and Cooling Rates

The results of the cooling experiments on the hypo-eutectic base alloy were similar to those obtained by Bardenheur and Zeyen,[12] who studied the effects of superheat on graphite formation in cast irons, and by Massari and Lindsay,[13] who quenched cast iron into water from various melting temperatures. Both groups of workers put forward the idea, originally suggested by Hanemann,[14] that undissolved graphite nuclei existed in the molten iron over a specific temperature range, above which the nuclei dissolved.

Piwowarsky,[15] however, showed that the coarse flake graphite in grey irons dissolved in a matter of seconds at temperatures just above the melting point. This, he indicated, was strong evidence against the possibility of undissolved graphite existing at even higher temperatures. He then proposed that the changes in the graphite formation due to melting temperatures were probably caused by a change in the molecular arrangement of carbon in the melt.

Though the physical picture of liquids is rather incomplete, X-ray diffraction work has shown the existence in liquids of a limited ordering of atoms, which decreases with increasing temperature.

Stewart and Morrow,[16] who studied the diffraction pattern of normal alcohols, called these groupings of atoms in the liquid ' cybotactic groups.' Menke[17] extended the study to metals and he found a short-range order existing in liquid mercury and gallium. Hendus[18] studied the structure of molten gold, gold–tin alloys, and other metals, and he, likewise, determined short-range order in the melts, which decreased with increasing temperatures.

The molecular arrangements of carbon in the melt, pictured by Piwowarsky, might be a similar type of short-range order of carbon atoms, or perhaps iron and carbon atoms, favourable to the formation of graphite. This favourable short-range order would decrease with increasing melting temperature and could be one of the rate determining factors controlling the graphite growth.

If the nucleation of the graphite is unchanged by an increase in melting temperature, the fine graphite obtained in the hypo-eutectic alloy melted at 1425° C. and cooled at the relatively slow rate can be attributed solely to the decrease in short-range order of the carbon atoms. However, the appearance of apparent primary graphite in the 5-g. remelted ternary alloy ingots of eutectic composition suggested the presence of graphite nuclei whose appearance is dependent on the melting temperature. The graphite particles observed in the hypo-eutectic alloy quenched from 1275° C. (Fig. 4*a*) and the nodules in the quenched structure of the eutectic alloy melted at 1200° and 1275° C. (Fig. 7*a*) also indicated the existence of graphite nuclei in the melt.

Considering the rapid rate of solution of the graphite above the liquidus, a possible explanation for the existence of this type of nucleus is necessary. Keverian[5] has suggested that a complex adsorption of oxygen might occur on graphite in cast irons. He pointed out how Langmuir,[19] after heating a graphite filament *in vacuo* and then exposing it to oxygen, found a stable adsorption of the oxygen on the graphite which could not be removed at any appreciable rate until the filament had been heated to 1927° C. *in vacuo*.

It is suggested that the nuclei might be either undissolved particles or a domain of high concentration of the short-range order of carbon atom groupings, whose dispersion is prevented by oxygen.

There were indications that there was a concentration of oxygen in the original ingots. The source of the oxygen was the oxidized Swedish iron. The appearance of internal chill in all except one of the original ingots of the ternary alloys melted under nitrogen was evidence of the incomplete removal of oxygen from the melts.

Thus the results of the hypo-eutectic cooling experiments can be interpreted as a function of two factors. Increasing the melting temperature both reduces the size and probably the number of graphite nuclei, and at the same time increases the randomness of distribution of the carbon atoms in the melt, with respect to their favouring graphite formation. This increase in disorder of the carbon atoms has a tendency to persist even with the relatively slow cooling rates from the 1425° C. melting temperature (Fig. 4*e*).

The presence of original austenite dendrites and the absence of primary graphite in the original 300-g. ingot of the alloy of eutectic composition showed that it had solidified slightly to the left of the eutectic trough as a hypo-eutectic alloy but the remelts at temperatures up to 1350° C. produced what appeared to be primary graphite. This suggested that the original melting temperature of the alloy was high enough to dissolve the graphite nuclei completely, but on remelting to a lower temperature the nuclei appeared and, together with the very high concentration of carbon in the melt, provided favourable conditions for the growth of the ' primary ' graphite when the alloy was cooled. The general changes in graphite formation due to the different melting temperatures and cooling rates were the same in this alloy as in the hypo-eutectic one.

Effects of Addition Elements

Since both sulphur and selenium promoted the growth of relatively coarse flakes and then refined the graphite, it was most probable that the mechanism determining these graphite structures was the same in both cases.

Examination of the bonding of the carbon atoms in the graphite lattice shows that the most favourable direction of growth is parallel to the hexagonal nets, rather than normal to them.[20] The ideal conditions for a nucleus of graphite to grow to a maximum flake size would be in a liquid (owing to the faster rate of diffusion in this state than in the solid one) where

there is a sufficiency of carbon atoms favourable to graphite formation and where a maximum time is allowed for growth.

Boyles[1] and LaPlanche[2] showed that the solidification of their Fe–C–Si alloys occurred in the following manner:

(i) Primary dendrites of austenite are precipitated and they continue to grow up to the eutectic solidification range
(ii) Crystallization of the eutectic liquid begins at centres that grow equally in all directions, forming a cell structure
(iii) There are two stages of segregation:
  (*a*) between the primary dendrites and the liquid
  (*b*) from the crystallization centres outward into the cell boundaries
(iv) The constituents formed during the freezing of the eutectic occupy the interstices of the dendrites.

Owing to the moderately fast cooling rate used for the addition series, the structure produced in the remelted hypo-eutectic alloy was a fine one consisting of the undercooled A.S.T.M. Type *D* graphite and small flakes (Figs. 4*b* and 5*a*). Three explanations of how sulphur (or selenium) could promote the growth of flake graphite are proposed:

(i) If, as Patterson[4] suggested, the addition of sulphur provides favourable heterogeneous nuclei, the transformation to a coarser graphite is explained by the earlier precipitation of the graphite and the longer time allowed for its growth. The objection to this is that it provides no explanation for the appearance of mesh graphite and eutectic carbide with subsequent increased additions of sulphur. It is true that sulphides are associated with many of the graphite flakes but they are also to be seen in contact with the mesh graphite and eutectic carbides
(ii) Since the eutectic crystallization starts at centres and grows radially outwards, an increase in the rate of growth of the graphite would permit a growing graphite particle to grow into the liquid ahead of the advancing front of the solidifying eutectic austenite. If the sulphur increased the rate of diffusion of the carbon atoms to the graphite nucleus, or perhaps increased the proportion of the carbon atoms in the eutectic liquid favourable for graphite growth, its growth rate would increase. In the solid state, however, the effect of sulphur is to reduce the diffusion rate of carbon
(iii) The same effect as in (ii) could be obtained if the rate of solidification of the austenite was decreased, since it is the relative rate of growth that is the important factor.

The most probable explanation is the last-named. The freezing sequence as determined by Boyles[1] shows that segregation occurs in two stages, and with as low a sulphur content as 0·001%, sulphides were found in the cell boundaries, originally the last liquid phase to solidify. Figure 18 shows some of these sulphides at a cell boundary in ingot 24, 0·005% S. Considering the fact that sulphur is evidently almost insoluble in the solid austenite, the reduction of growth rate by an addition of sulphur would be due to the concentration of rejected sulphur atoms at the surface of the growing eutectic austenite crystal. This in effect would reduce the concentration of iron and carbon atoms in the mother liquid that is in contact with the solid austenite. An analogous process has been described by Wells[21] in discussing the growth of a crystal from solution. He pointed out that when a crystal of an unsolvated material grows, the solvent layer at the surfaces must be removed before the next layer of molecules can be incorporated into the crystal. Another factor that could decrease the solidification rate of the austenite is a decrease in its rate of nucleation.

The thermal arrests that Hanemann and Schildkotter[22] obtained on Fe–C–S alloys, of cast-iron composition in regard to the carbon, showed that the temperature of the eutectic crystallization was lowered with increasing sulphur content. Levy[11] also noted that the eutectic arrest occurred at lower temperatures as the sulphur increased towards 0·8%. From the cooling curves (Figs. 22 and 23) it would appear that at the arrest where the graphite and eutectic austenite are precipitated, there were no major differences between the solidification rates that produced the undercooled and the flake type graphite, respectively. However, to create the conditions as outlined above, it would not require a radical alteration of the solidification rate of the austenite. If the finer graphite in the 'no addition' ingot was the result of the austenite growth rate being equal to, or slightly greater than, that of the graphite, it would only be necessary to decrease the solidification rate of the eutectic austenite by a small amount relative to that of graphite for the flake structure to be produced.

The 0·025% S curve did show a slight increase in the time of eutectic solidification, which could have been due to a decrease in the rate of solidification of the austenite. This was not observed in the 0·01% Se cooling curve, which would be expected if the decrease in the austenite solidification rate induced by selenium was less than that of the sulphur. The same factor would also be responsible for the production of the coarser flake graphite by the sulphur.

In the 5-g. series of melts, with sufficiently high additions of sulphur or selenium, refinement of the graphite structure took place with the appearance of the mesh type. Coincident with this, at the lower melting temperatures, the black powder appeared on the surface of the ingots.

The values of the heats of formation of the iron monosulphide, selenide, and telluride given by Kubaschewski and Evans[23] indicate that the bond energy between the iron and addition elements is lowest with tellurium and highest with sulphur; selenium has an intermediate value. The tendency to produce the black powder was greatest with tellurium, followed by selenium and then by sulphur. Apparently there is a connection between the weakness of bonding of the atoms of the addition element with iron and its ability to remove the graphite from the melt. Although Buttner *et al.*[24] concluded that sulphur decreased the interfacial energy between a cast-iron melt and a graphite crucible, it is unlikely that graphite particles would be ejected from the melt unless some surface phenomenon took place whose occurrence prevented a 'wetting' between the two; the low density of the graphite relative to the melt would facilitate its separation.

Compared with the sulphur, selenium coarsened the graphite structure over only a small range of additions before the mesh graphite was produced. This would be consistent with the relative values of the elements as graphite nuclei removers. If the effect of the addition elements is twofold, decreasing on the one

hand the solidification rate of the eutectic austenite during the cooling and, on the other, changing the melt conditions so that the graphite nuclei are removed, the range of additions over which the flake graphite occurs is dependent on when the second effect becomes operative. The fact that the coarsening of the graphite by selenium did not reach the magnitude achieved by the sulphur would then be due to their relative effects on the eutectic austenite solidification.

The cooling curve alloys with the higher sulphur and selenium additions were covered with a thin layer of the black powder. The cooling curves (Figs. 22 and 23) suggested that the mesh-type structures obtained with these additions were the product of a solidification that occurred at a lower temperature range than those which produced the other forms of graphite. The marked undercooling is consistent with the removal of graphite nuclei and the slow rate of solidification of the austenite.

From the above conjectures, the effects of further sulphur and selenium additions in the 5-g. ingot series (Figs. 3 and 20) can be considered as follows.

With the sulphur additions, if the undercooling became large enough, a critical stage would be reached where, because of the low temperature range of eutectic solidification and perhaps a decreased rate of diffusion of the carbon, eutectic carbide crystallized as the predominant interdendritic carbon phase. With the higher melting temperatures, less sulphur was required to produce a predominantly carbide structure, perhaps owing to the higher state of disorder of the carbon atoms in the melt, which would mean a slower potential rate of graphite growth.

For the selenium additions, although some eutectic carbide did appear with the maximum addition at the two lower melting temperatures, the type of structure that replaced the mesh graphite was the small spherulitic and quasi-flake graphite, and not the carbide. Many of the quasi-flakes and spherulites contained relatively large inclusions (Fig. 12*b*). The size of the graphite indicated that it was formed at a relatively low temperature and did not have time to grow. The isolated spherulites seen with the mesh graphite were larger and appeared to have been formed at the edge of the growing austenite dendrite, whereas the globular and quasi-flake structure was interdendritically situated.

From the fact that a high percentage of this graphite contained inclusions, it could be interpreted that the selenides have provided favourable nuclei on which the graphite grows. There must, however, be other factors involved, since the inclusions formed by the other two addition elements are similar in crystal structure and lattice dimensions to the selenide but only the selenium produces the globular and quasi-flake structure. Further selenides were also observed within the mesh type graphite.

As the cooling curves have indicated, the differences in the effects of the selenium and sulphur at the higher additions might arise from the different degrees of change in the temperature range and rates of eutectic solidification. As previously noted, when mesh graphite was produced, sulphur lowered the temperature arrest more than the selenium did, but the former showed a faster rate of solidification than the Se alloy.

The maximum flake size obtained in an addition series decreased with an increased melting temperature. This could be due to the smaller size of the interdendritic eutectic pools and possibly the higher degree of randomness of the carbon atoms in the melt, which decreased the rate of growth of the graphite. The fact that less flake graphite was obtained at the highest melting temperature also indicates that there may not have been a sufficient number of nuclei present in the melt to supply each interdendritic pool.

The decrease with higher melting temperatures of the amount of the black powder that appears on the ingot was also probably due to the reduction in the number of graphite nuclei in the melt.

The fine flake graphite in the eutectic cell boundaries of the original ingots was probably due to the decrease of the rate of solidification of the austenite in the very last liquid to solidify owing to the segregation of the small amounts of sulphur (0·001–0·005%) to these regions.

The same effect of segregation of the sulphur explains the rosette pattern of graphite observed in some of the structures produced by the low additions (Fig. 19). The centre of the rosette consisted of an undercooled graphite area with flakes of graphite radiating from this fine structure. According to LaPlanche's quenching experiments,[2] the fine structure is located at the centre of the eutectic cells and the flakes grow radially as solidification proceeds. This is consistent with the segregation of sulphur towards the remaining liquid on a spherical front and, when the concentration of the sulphur in the liquid becomes sufficiently high, flake graphite starts forming owing to the decrease of the solidification rate of the eutectic austenite from the remaining liquid. Initially the eutectic austenite started growing at a rate equal to or greater than that of the graphite, but as the concentration of the sulphur in the remaining liquid increased, the rate of growth of the graphite became the relatively faster one.

The refinement of the graphite structures by small additions of tellurium at the two lower temperatures indicates that this element initially changed the solidification mechanism in a manner opposite to that of the sulphur or the selenium, after which it acted somewhat similarly to these two elements. If there were present in the base hypo-eutectic alloy small quantities of elements such as sulphur and oxygen, which were already affecting the nucleation of the graphite or the rate of solidification of the austenite, the first small additions of tellurium might have entered into combination with these elements and neutralized its own effects as well as those of other elements. This would then correspond with the initial graphite refining. An excess of tellurium over that required to neutralize these active elements would then have a direct 'tellurium' effect which would depend on the amount of that element retained in the melt.

In cast irons, it has been suggested by Von Keil *et al.*[25] that a sub-microscopic silicate slime nucleates the melt to give coarse flake graphite. It is doubtful if heterogeneous nuclei of a silicate composition play any such role in the flake-producing effect of sulphur

and selenium on the pure ternary alloys, since Williams[3] found that sulphur had the same effect on a very pure iron–carbon alloy containing no silicon. In this latter alloy the possibility of having silicate inclusions would be almost nil.

Boyles[1] and LaPlanche[2] expressed the changes in graphite structure by sulphur in terms of an increase in carbide stability. Boyles did not notice any depression of the eutectic crystallization temperature when 0·1% sulphur was included in the charge. Although the carbide theory gives an adequate explanation in terms of the rates of growth of the graphite relative to that of the austenite, it includes the assumption that the eutectic liquid initially freezes as austenite and carbide, and the carbide then breaks down almost immediately to austenite and graphite. This implies the existence of carbon in the liquid as carbide.

But the evidence indicating the existence of graphite nuclei in the melt—the graphite particles in the quenched structures and also the graphite found on the ingots with the high additions—is sufficient to discard the carbide stability theory and utilize a less complex picture of nucleation and growth.

The terms ' eutectic solidification ' and ' eutectic ' have been used to describe the solidification process and products in the trough of the Fe–C–Si system which originates at 4·3% of carbon on the Fe–C side of the diagram. While it is convenient to treat the effects of the addition elements in terms of reference to a binary eutectic, it must be pointed out that in this case a multi-component system is being considered, and it is known here that the ' eutectic ' is not an invariant point.

CONCLUSIONS

It is suggested that the changes effected in the graphite formation of Fe–C–Si alloys by the addition of sulphur and selenium are due to the modifications in the nucleation of the graphite and the growth rate of ' eutectic ' austenite.

The form of the main interdendritic carbon phase is apparently determined, in the presence of graphite nuclei, by the relative rates of growth of the solid austenite and the graphite. In the absence of graphite nuclei, the carbon phase produced is dependent on the magnitude of the depression of the temperature range of solidification of the eutectic liquid and some other factors, including possibly the lattice structure of the inclusions.

Increasing the melting temperature from 1275° to 1425° C. affects the graphite formation in a manner which suggests a decrease in the number of graphite nuclei and a reduction in the rate of growth of the graphite with increasing melting temperature.

In the case of the tellurium additions, the results are not as reproducible as with the other two elements, probably because of the irregular losses of tellurium from the molten alloys. At the lower melting temperatures, the graphite is first refined with low additions of tellurium and then it coarsens with further additions. Unless the small additions first neutralize the effects of small amounts of other elements this effect is rather difficult to interpret in the light of the sulphur and selenium results. The mesh graphite structure produced with tellurium is probably formed by the same mechanism as in the case of the other two addition series.

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Ingot Heat Conservation

THE COOLING OF RIMMING-STEEL INGOTS BETWEEN TEEMING AND STRIPPING

By M. D. Ashton, B.Sc., R. F. Perkins, L.I.M., and L. H. W. Savage, M.Sc., F.R.I.C., M.Inst.F.

SYNOPSIS

A method is described of reducing fuel consumption in soaking pits, increasing pit availability, and increasing mould life by stripping all ingots at the earliest practicable time. This method is based on a series of investigations which have been carried out on 8- and 15-ton rimming-steel ingots.

The most recent series of these investigations have confirmed that time from start of teem and initial mould temperature are the most significant factors influencing the heat loss from 15-ton rimming-steel ingots. Increase of initial mould temperature causes a decrease in the rate of heat loss.

The initial mould temperature can be closely estimated from the time which has elapsed since the mould was stripped. By making certain simplifying assumptions the average thickness of solidified steel can be calculated and related to time from start of teem and initial mould temperature.

A comparison of the results obtained from 15-ton ingots with those from earlier work on 8-ton ingots shows that increasing ingot size

(*a*) Decreases the rate of cooling due to a decrease in the ratio of surface area to mass; and

(*b*) Increases the magnitude of the effect of initial mould temperature. 1188

FUEL SAVING in soaking pits is dependent on ingots being stripped and charged in the hottest possible condition compatible with safe handling. Heating times are consequently short, resulting in high pit availability and, because the ingots remain in the moulds for the minimum possible time, mould life should be high. The cooling of steel ingots is therefore being studied by the Fuel Technology Section of B.I.S.R.A. to learn more about the influence of time from teem to strip and other variables upon the thermal condition of the ingots.

The factors influencing the heat loss from 8-ton rimming-steel ingots cooling in a casting pit that were found to be significant in 25 trials[1, 2] were time from teem to strip and initial mould temperature. A first series of 12 trials on 15-ton bogie-cast ingots,[3] whilst confirming the effects of these variables, was not in itself sufficient to determine the magnitude of the effect of initial mould temperature and, because of this, a second series of trials has been carried out.

The objects of this paper are:

(1) To discuss the application of the results obtained on 8- and 15-ton ingots to works practice, in order to improve soaking-pit fuel consumption and pit availability

(2) To describe the experimental procedure in the second series of trials on 15-ton ingots, which differed slightly from the first series

(3) To present the results obtained from all the trials involving 15-ton ingots

(4) To compare these results with those obtained for 8-ton ingots and see how far interpolation and extrapolation for different ingot weights can be carried out.

List of Symbols

H_s	Heat loss from steel, cal./g. or therms/ton
H'	Superheat, cal./g.
K, A	Constants
F_n	Instantaneous net heat flux, cal./sq.cm. sec.
M	Mass of steel in mid-height section, g.
P	Surface area of ingot section, sq. cm.
S	Mean thickness of solid shell, cm. or in.
t	Time from start of teeming, min.
t'	Time from stripping, hr.
ϵ	Emissivity
σ	Stefan's constant; standard deviation
ρ	Density of steel
θ	Initial mould temperature, ° C.
θ_1	Liquidus temperature of steel, ° C.
θ_m	Mould temperature, ° C.
θ_0	Average steel surface temperature, ° C.

APPLICATION TO WORKS PRACTICE

It has been found expedient in many works to stipulate an empirical time from end of teem before a cast of ingots can be moved or stripped. This time varies within individual works for ingots of different weights and also varies between different works.[4]

In establishing its magnitude the aim has usually been:

(i) To allow any cast to be moved or stripped after this time without likelihood of
  (*a*) deformation or bleeding of ingots
  (*b*) penetration of the ingot top by the stripper crane ram

(ii) To allow for any possible malpractice of stripping first the last ingot to be teemed.

Investigations by Savage and Fowler,[2] Sarjant and Slack,[5] and others[6] have confirmed that if an ingot has had a long track time, its centre will have cooled below rolling temperature upon charging to a soaking pit and a prolonged heating time will be required to restore it to rolling temperature. A study of practice in several works[7] also showed that the effects of long track times, with consequent long heating times in soaking pits, are self-aggravating and, conversely, attempts to improve track times lead to shorter heating times and increased pit availability.

At the time of tapping, the heat content of steel is about 4½ therms/ton in excess of that required at the rolling mill. Under the most favourable circumstances it has been observed that ingots have been

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Mr. Ashton and Mr. Perkins are members of the Fuel Technology Section of the Association's Physics Department; Mr. Savage is Head of the Section.

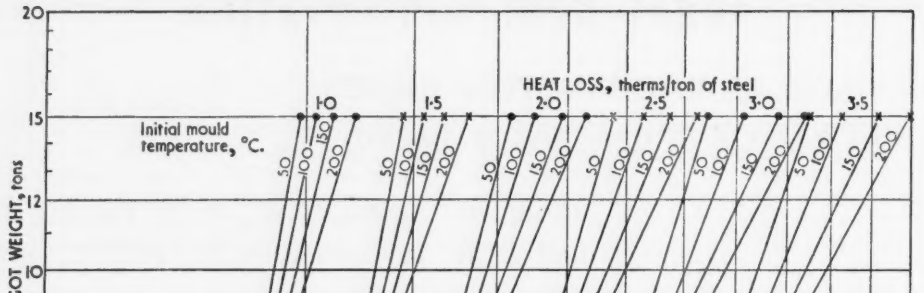

Fig. 1—Effect of initial mould temperature upon heat loss from 8- and 15-ton ingots

stripped according to empirical rules when they have lost 3 therms/ton from the mid-height section. However, the heat loss from the whole ingot will be somewhat greater than that at the mid-height section and can be taken as nearly 4 therms/ton. A further quantity of heat estimated at about 1 therm/ton is lost during the 10–20 min. required in current stripper-bay practice, for transfer into soaking pits. Consequently only these ingots will be charged with an average heat content at or in excess of that required for rolling and will require only sufficient time in the pits for temperature equalization. All others will be cooled below rolling heat and will require many additional therms, owing to the inefficiency of soaking pits as reheaters as well as to longer heating times.

The investigations described in this and previous papers have established:

(i) The rate of cooling of 8- and 15-ton ingots
(ii) The effect of initial mould temperature upon this rate
(iii) The relationship between initial mould temperature and the time from strip to teem.

The effect of initial mould temperature upon the heat loss from 8- and 15-ton ingots is illustrated in Fig. 1, and it is considered that the data presented in this graph can be interpolated for intermediate weights of ingots with sufficient accuracy for works use. However, extrapolation beyond the range investigated may be liable to errors from causes not yet ascertained.

Assuming that all ingots can be stripped when they have lost 3 therms/ton at the mid-height section, it is possible to deduce the time between start-teem and start-strip from the time between *previous* stripping of the mould and start of teem. This is illustrated in Fig. 2 for 8- and 15-ton ingots. Times for other ingot sizes can also be interpolated from the diagram.

Since the rate of solidification of the steel decreases with increase of initial mould temperature, empirically fixed teem-to-strip times are necessarily based on safe times for the hottest moulds used in the works. When the moulds are initially cold, ingots are stripped later than necessary, thus requiring longer heating

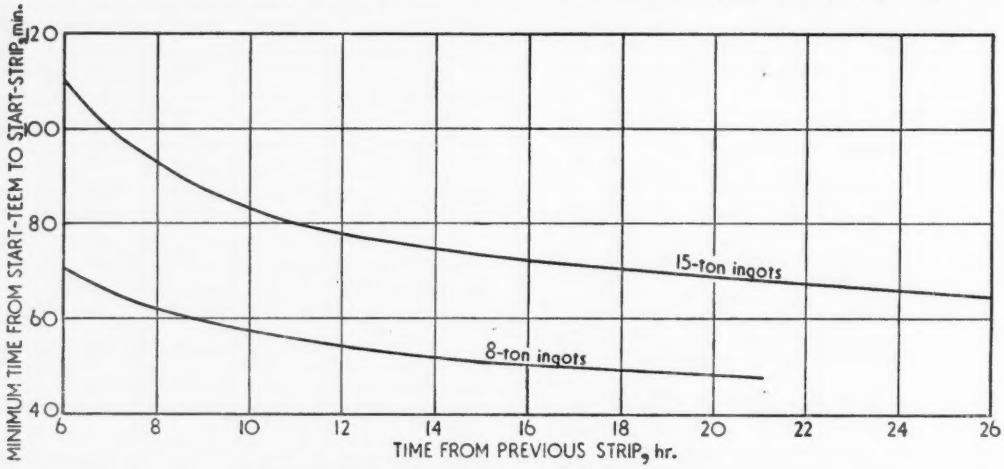

Fig. 2—Estimated minimum time for stripping

times, decreasing pit availability, and increasing fuel consumption. By use of Fig. 2 ingots can be stripped and charged in the same thermal condition. They will then require the same heating time, irrespective of any difference in track time, and current works practice will be improved.

Heating practice might have to be modified since, if a cast of hot ingots is charged to a pit and full gas turned on immediately, there is a likelihood of the ingots being sent for rolling when their centres have not fully solidified, and blistered rolled products will result. This could be remedied within individual works by having an initial soaking period in the pits with the fuel input reduced to a rate to be established by experiment and should not lead to any decrease in pit availability.

The minimum stripping times suggested in Fig. 2, which are based on a heat loss from the mid-height section of 3 therms/ton, might be reduced still further. This could eventually result in ingots being charged to soaking pits in such a condition that no fuel would be required other than that to offset heat losses from the pit structure.

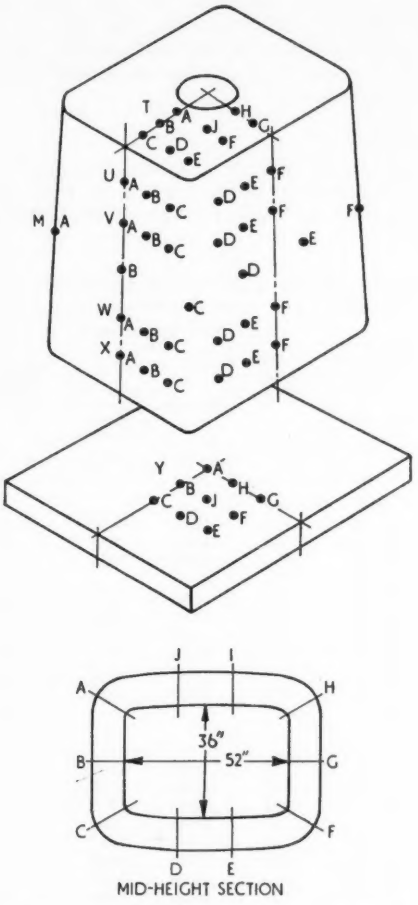

Fig. 3—Location of thermocouple plugs in test mould and bottom plate

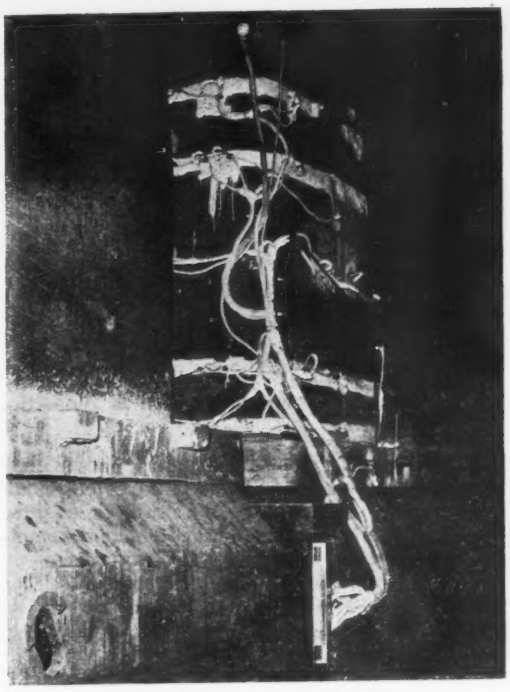

Fig. 4—Ingot mould showing connections to thermocouple plugs and to switchboxes

TRIALS ON 15-ton INGOTS

Procedure for Second Series of Trials

Distribution of Thermocouples in the Test Mould

As in previous work, measurements at the mid-height plane of the mould were made using 10 thermocouple plugs each containing four thermocouples.

To obtain data for calculating temperature distributions within the ingot and heat transfer perpendicular to the mid-height plane, which will form the subject of another paper, a further 87 thermocouples distributed between 33 plugs were inserted in a vertical quarter-section of the mould and 23 thermocouples distributed between 9 plugs were inserted in a quarter-section of the bottom plate. In addition, a plug containing two thermocouples was inserted through the mould cap and when the cap was removed, before the train left the casting bay, temperatures of the exposed surface of the ingot neck were measured by means of two thermocouples located at the ends of two legs of a steel tripod. The arrangement of thermocouple plugs in the mould and bottom plate is shown in Figs. 3 and 4.

With the object of directly measuring temperatures in the core of an ingot, an attempt was made during one of the trials to insert an alumina sheath containing a rare-metal thermocouple through the top of the mould into the steel to a depth of 2 ft. 6 in., but this was not successful.

Recording of Mould and Bottom-Plate Temperatures

Temperatures in the mould and bottom plate were recorded from the time when teeming into the test

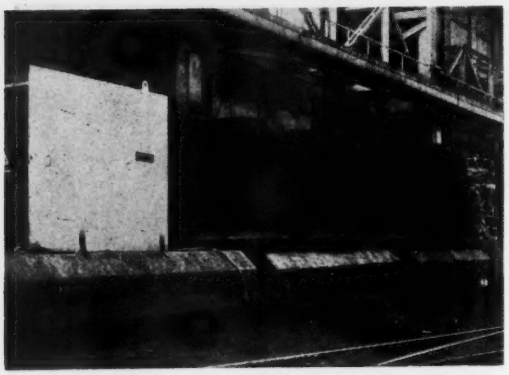

Fig. 5—Mould train showing position of connecting cable

mould began until just before stripping, and, in order to provide data upon the cooling of the empty mould after stripping, temperatures were also recorded intermittently after the mould had been reset on the empty train on the latter's return from the soaking pits.

Three twelve-point recorders with auxiliary selector switchboxes were used. Those temperatures in the mould which were expected to change rapidly were recorded on a high-speed recorder using a 48-point switchbox,[8] 2½ min. being required for a complete printing cycle. The remaining mould and mould-cap temperatures were recorded on a second high-speed recorder using 96 points of a 144-point switchbox,[9] and bottom-plate temperatures were recorded on a medium-speed recorder using a 24-point switchbox. Both these switchbox recorder combinations had a printing cycle time of 5 min.

Location of Instruments

In all 8 trials of this series, the test mould was the fourth of the twelve 15-ton moulds on the train. Thermocouple connections passed directly to the switchboxes which were in a protective housing situated at the front end of the bogie upon which the test mould stood. A cable, which was fastened along the train to the sides of the bogies, connected the switchboxes to a control panel and the recorders, which were mounted in a shelter on a bogie at the front of the train.

This arrangement of the experimental equipment is shown in Fig. 5. The instrumentation and the power supplies for the recorders and switch boxes are described in detail in Appendix I.

Calculation of Heat Loss from Steel

For the mid-height section, the heat gain by the mould was calculated by the method previously used,[1, 3] which neglected heat transfer perpendicular to the mid-height plane. The value of steel density used was that appropriate to the ingot weight (Appendix II). The surface heat loss from the mould was estimated from surface temperature gradients, and added to the heat gain by the mould to give the heat loss by the steel.

Results of Trials

A summary of the initial mould temperatures and other conditions for the test mould for both series of trials is given in Table I. The values obtained for

Table I

TRIALS ON 15-ton INGOTS: SUMMARY OF CONDITIONS FOR TEST MOULD

Trial No.	Cast No.	Date of Tap	Time of Tap	Time from Tap to Teem,* min.	Time from Teem to Strip, min.	Time from Previous Tap to Tap hr. min.	Time from Previous Strip to Tap hr. min.	Initial Mould Temp., °C.	Steel Temperature, °C.		Position of Mould on Train
									Furnace	Start of Teem (Estimated)	
		May 1953									
1	G 69	6	11.40	19	136	...†	...†	49	...	...	1
2	L 815	6	22.18	20	177	10 38	08 03	206	1585	1550	1 reversed
3	G 71	7	12.58	23	147	14 40	11 28	170	1590	1553	2
4	L 817	8	03.04	20	124	14 06	11 16	184	1590	1555	2
5	N 478	8	18.12	19	124	15 08	12 44	148	...	...	3
6	J 45	9	07.42	22	191	13 30	11 07	186	1560	1524	3 reversed
7	K 948	9	23.40	25	170	16 00	12 25	155	1605	1566	5
8	M 491	10	12.30	28	152	12 50	09 35	211	...	...	5
9	L 822	11	04.10	34	129	15 40	12 45	167	1600	1555	10
10	L 823	11	17.00	31	99	12 50	10 07	196	1590	1547	10 reversed
11	K 953	12	04.18	34	118	11 15	09 05	215	1595	1550	11
12	H 959	13	13.05	35	105	32 47	30 15	49	...	...	11
		June 1954									
13	N 48	10	12.18	27	160	...†	...†	32	1600	1560	4
14	K 504	11	07.19	26	180	19 00	15 54	110	1590	1550	4
15	N 52	11	21.03	24	333	13 44	10 18	182	1600	1562	4
16	N 61	15	07.24	24	164	...†	...†	40	1605	1567	4
17	H 579	16	08.50	24	106	25 26	22 18	89	1600	1562	4
18	O 913	16	18.30	25	125	9 40	07 30	220	1595	1556	4
19	N 65	17	01.29	26	112	7 00	04 29	324	1595	1555	4
20	N 67	17	19.25	24	123	17 56	15 38	128	1600	1562	4

* First splash in ladle to first splash in mould † Over 72 hr.

heat lost by steel, heat gained by mould, and surface heat loss from the mould are tabulated in Table II and illustrated in Fig. 6.

Influence of Independent Variables on Heat Loss from Steel

The results for 19 casts of the two series considered showed that for the mid-height section, the heat loss from the steel (H_s) was approximately proportional to the square root of time from start of teeming (t):

$H_s = 8{\cdot}20\sqrt{t}$ cal./g. .....(Standard deviation $\sigma = 0{\cdot}83$)

or $= 0{\cdot}33\sqrt{t}$ therms/ton (,, ,, $\sigma = 0{\cdot}033$)

The value of $H_s/\sqrt{t}$ was found to vary with initial mould temperature (θ) and over the range normally found in practice (20–200° C.) it could be expressed by a linear regression:

H_s, cal./g.

$$\frac{H_s}{\sqrt{t}} = 9{\cdot}37\left(1 - 0{\cdot}96\,\frac{\theta}{1000}\right) \ldots\ldots\ldots\ldots (\sigma = 0{\cdot}67)$$

or H_s, therms/ton

$$\frac{H_s}{\sqrt{t}} = 0{\cdot}38\left(1 - 0{\cdot}96\,\frac{\theta}{1000}\right) \ldots\ldots\ldots\ldots (\sigma = 0{\cdot}027)$$

It was also found to vary with time from start of teeming, and the best-fit regression equation at a significance level of 1 in 20 was found to be:

H_s, cal./g.

$$\frac{H_s}{\sqrt{t}} = 8{\cdot}10 + 0{\cdot}449\left(\frac{t}{10}\right) - 0{\cdot}0287\left(\frac{t}{10}\right)^2 - 0{\cdot}895\left(\frac{\theta}{100}\right) \ldots\ldots\ldots\ldots (\sigma = 0{\cdot}51)$$

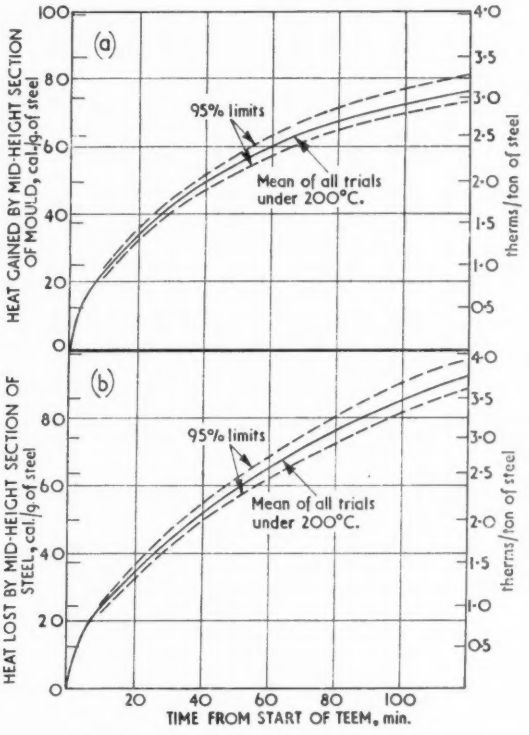
(a)
(b)
95% limits
Mean of all trials under 200°C.
HEAT GAINED BY MID-HEIGHT SECTION OF MOULD, cal./g. of steel
HEAT LOST BY MID-HEIGHT SECTION OF STEEL, cal./g. of steel
therms/ton of steel
TIME FROM START OF TEEM, min.

Fig. 6—Heat gained and lost *v.* time

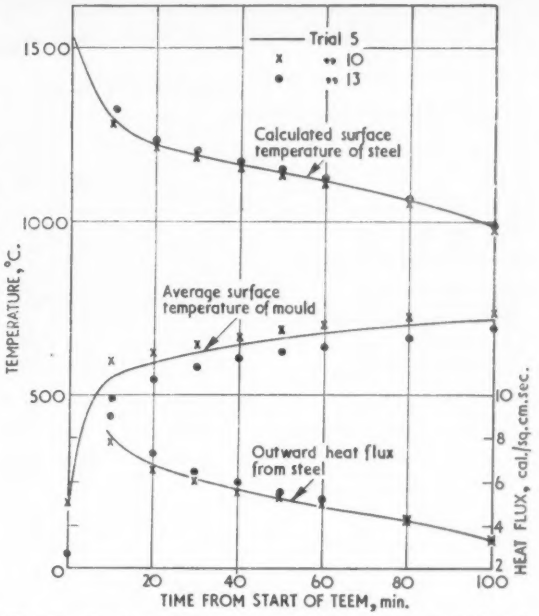

Fig. 7—Surface temperature of ingot and mould and outward heat flux from steel

or H_s, therms/ton

$$\frac{H_s}{\sqrt{t}} = 0{\cdot}325 + 0{\cdot}180\left(\frac{t}{100}\right) - 0{\cdot}115\left(\frac{t}{100}\right)^2 - 0{\cdot}036\,\frac{\theta}{100} \ldots\ldots\ldots\ldots (\sigma = 0{\cdot}020)$$

The linear relationship between ($H_s/\sqrt{t}$) and θ was not found to be significant if the range of θ was extended beyond 200° C., but insufficient trials were carried out above this temperature.

Rate of Solidification of Steel

For a given total heat loss the mean thickness of the solidified shell (S), and hence the rate of solidification of the steel at the mid-height section, was estimated for three trials covering the range of θ by the method previously used.[2] The thickness solidified can be expressed by the formulæ:

$$S = 3{\cdot}3\left(1 - \frac{\theta}{1000}\right)\sqrt{t} \text{ cm.}$$

$$= 1{\cdot}3\left(1 - \frac{\theta}{1000}\right)\sqrt{t} \text{ in.}$$

The results are illustrated in Figs. 7 and 8. The steps in the calculations, including a slight modification in the calculation of net heat flux to allow for the effect of initial mould temperature, are given in Table III.

Rate of Cooling of Mould

Data obtained on the cooling of the empty mould in both series of trials were combined to derive an empirical rule relating mould temperature θ_m to time. Temperatures in the mould, though widely scattered at the time of stripping, were found to have evened out after 3 hr. and could then be related to an exponential function of time (t') from stripping:

$$\theta_m = 438{\cdot}0e^{-0{\cdot}0726t'} \ldots\ldots\ldots (\sigma = 1{\cdot}1° \text{ C.})$$

This relation is illustrated in Fig. 9.

Table II

TRIALS ON 15-ton INGOTS: TEST RESULTS

	Trial No.	Time from Start of Teem, min.										Initial Mould Temp., °C.	K in $H_s = K\sqrt{t}$
		5	10	20	30	40	50	60	80	100	120		
Heat loss from steel	1	15·0	21·7	32·2	41·8	49·7	57·2	63·5	74·5	83·8	91·1		
Heat gain by mould		15·0	21·7	32·0	41·2	48·5	55·2	60·5	68·9	75·3	79·3	49	7·79
Convection and radiation loss		0·0	0·0	0·6	1·2	2·0	3·0	5·5	8·5	11·8			
Heat loss from steel	2	16·1	21·7	31·7	39·4	46·1	53·4	59·5	68·1	75·8	82·0		
Heat gain by mould		16·0	21·4	30·9	37·8	43·4	49·4	54·1	59·5	63·7	66·1	206	7·35
Convection and radiation loss		0·1	0·3	0·8	1·7	2·8	4·0	5·4	8·6	12·1	15·9		
Heat loss from steel	3	17·4	21·7	30·5	39·2	47·0	54·2	63·5	73·3	81·2	88·2		
Heat gain by mould		17·3	21·5	29·8	37·8	44·7	51·7	57·6	64·2	68·6	71·8	170	7·55
Convection and radiation loss		0·1	0·2	0·7	1·4	2·3	3·5	5·9	9·1	12·6	16·4		
Heat loss from steel	4	14·8	20·4	31·6	40·4	47·9	55·8	62·2	71·9	80·0			
Heat gain by mould		14·7	20·2	30·8	38·9	45·4	52·1	57·2	63·7	68·3		184	7·51
Convection and radiation loss		0·1	0·2	0·8	1·5	2·5	2·6	5·0	8·2	11·7			
Heat loss from steel	5	17·4	23·1	34·0	43·3	51·3	59·6	66·2	75·2	83·3			
Heat gain by mould		17·4	22·9	33·3	42·0	49·1	56·1	61·4	67·1	71·7		148	8·06
Convection and radiation loss		0·0	0·2	0·7	1·3	2·3	3·5	4·9	8·1	11·6			
Heat loss from steel	6	13·3	19·4	39·0	37·8	46·4	54·2	61·7	71·6	80·2	87·0		
Heat gain by mould		13·2	19·2	38·3	36·4	43·9	50·5	56·5	63·1	67·9	70·6	186	7·29
Convection and radiation loss		0·1	0·2	0·7	1·4	2·5	3·7	5·1	8·5	12·3	16·4		
Heat loss from steel	7	16·2	21·1	31·9	41·6	49·7	58·0	65·3	76·5	84·6	93·0		
Heat gain by mould		16·1	20·8	31·3	40·3	47·4	54·5	60·3	68·3	72·8	77·2	155	7·83
Convection and radiation loss		0·1	0·3	0·6	1·3	2·4	3·5	5·0	8·2	11·8	15·8		
Heat loss from steel	8	15·5	(22·4)	31·7	39·7	49·1	56·6	62·4	72·1	79·8	86·5		
Heat gain by mould		15·4		30·9	38·0	46·3	52·5	56·8	63·0	66·9	69·3	211	7·58
Convection and radiation loss		0·1		0·8	1·6	2·7	4·1	5·6	9·1	12·9	17·2		
Heat loss from steel	9	14·2	20·1	31·0	41·0	49·4	57·7	64·6	74·1	81·1	87·2		
Heat gain by mould		14·1	19·9	30·3	39·6	47·0	54·0	59·4	65·6	69·0	71·1	167	7·65
Convection and radiation loss		0·1	0·2	0·7	1·4	2·4	3·7	5·2	8·5	12·1	16·1		
Heat loss from steel	10	(14·0)	20·9	30·6	39·6	46·9	53·9	61·6	71·4	79·0			
Heat gain by mould			20·7	29·9	38·1	44·3	50·0	56·1	62·4	66·1		196	7·35
Convection and radiation loss			0·2	0·7	1·5	2·6	3·9	5·4	9·0	12·9			
Heat loss from steel	11	(14·9)	21·6	32·1	41·3	50·0	57·3	64·0	72·8	79·9			
Heat gain by mould			21·3	31·3	39·6	47·2	53·2	58·4	63·6	66·9		215	7·67
Convection and radiation loss			0·3	0·8	1·7	2·8	4·1	5·6	9·2	13·0			
Heat loss from steel	12	18·4	24·7	35·1	44·5	53·4	60·6	67·1	75·5				
Heat gain by mould		18·4	24·7	34·8	43·6	51·8	57·9	63·3	69·0			49	8·28
Convection and radiation loss		0·0	0·0	0·3	0·9	1·6	2·6	3·8	6·5				
Heat loss from steel	13	18·6	26·3	40·4	49·9	58·2	65·2	71·8	84·5	93·0	101·3		
Heat gain by mould		18·6	26·3	40·2	49·2	56·6	62·6	67·8	76·1	81·1	85·4	32	9·11
Convection and radiation loss		0·0	0·0	0·2	0·7	1·6	2·6	4·0	8·4	11·9	15·9		
Heat loss from steel	14	15·9	24·3	36·9	47·0	56·1	64·1	68·6	79·5	89·0	96·4		
Heat gain by mould		15·9	24·3	36·5	46·0	54·1	60·9	63·9	71·5	77·2	80·5	110	8·63
Convection and radiation loss		0·0	0·0	0·5	1·0	2·0	3·2	4·7	8·0	11·8	16·0		
Heat loss from steel	15	18·1	24·0	35·1	46·5	55·0	61·2	66·6	76·0	(86·6)			
Heat gain by mould		18·0	23·7	34·2	44·7	52·0	56·7	60·5	66·2			182	8·32
Convection and radiation loss		0·1	0·3	0·9	1·8	3·0	4·5	6·1	9·8				
Heat loss from steel	16	23·5	29·7	40·4	53·1	59·5	66·9	73·3	83·5	92·1	99·7		
Heat gain by mould		23·5	29·7	40·2	52·4	58·0	64·3	69·5	76·8	81·8	85·6	40	9·37
Convection and radiation loss		0·0	0·0	0·2	0·7	1·5	2·6	3·8	6·7	10·3	14·1		
Heat loss from steel	17	20·3	26·6	37·8	48·4	58·6	66·0	72·2	82·8	(93·0)			
Heat gain by mould		20·3	26·6	37·6	47·6	56·8	62·9	67·7	74·9			89	9·01
Convection and radiation loss		0·0	0·0	0·2	0·8	1·8	3·1	3·1	4·5	7·9			
Heat loss from steel	18	19·4	25·4	36·6	46·4	54·9	61·3	67·1	(77·3)	(86·7)			
Heat gain by mould		19·2	24·9	35·3	44·0	50·9	55·9	59·8				220	8·58
Convection and radiation loss		0·2	0·5	1·3	2·4	4·0	5·4	7·3					
Heat loss from steel	19	20·3	26·9	38·2	46·0	52·5	58·1	64·2	73·3	(80·8)			
Heat gain by mould		19·9	25·8	35·8	42·3	47·1	50·8	54·7	59·4			324	8·31
Convection and radiation loss		0·4	1·1	2·4	3·7	5·4	7·3	9·5	13·9				
Heat loss from steel	20	16·1	25·9	37·6	48·6	56·9	64·9	70·3	80·3	(95·0)			
Heat gain by mould		16·0	25·7	37·0	47·0	54·4	61·0	64·9	71·4			128	8·89
Convection and radiation loss		0·1	0·2	0·6	1·6	2·5	3·9	5·4	8·9				
Mean heat loss from steel H_s, cal./g.		16·9	23·3	34·2	43·7	51·8	59·3	65·7	75·7	84·5	91·2		
Standard deviation		2·6	2·7	3·6	4·4	4·5	4·3	3·9	4·6	5·6	6·3		
Standard deviation (% of H_s)		15·4	11·6	10·5	10·0	8·7	7·3	5·9	6·1	6·6	6·9		
Mean heat gain by mould		16·8	22·6	33·8	43·3	49·3	55·5	60·4	67·0	70·88	75·7		

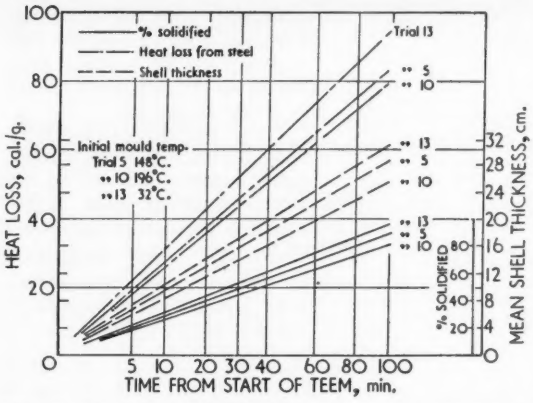

Fig. 8—Heat loss, shell thickness, and percentage solidified

TRIALS ON 8- AND 15-ton INGOTS: DISCUSSION OF RESULTS

Heat Loss from Steel

The heat loss from steel has been shown to be a function of time from start of teem and initial mould temperature. For 15-ton ingots, equations for heat loss have been given in the preceding section. Previous work[1, 2] has shown that the heat loss from 8-ton rimming-steel ingots can be roughly represented by (H_s, cal./g.):

$$\frac{H_s}{\sqrt{t}} = 9{\cdot}76$$

or with slightly greater accuracy by

$$\frac{H_s}{\sqrt{t}} = 11{\cdot}1\left(1 - 0{\cdot}75\,\frac{\theta}{1000}\right)$$

and the best-fit regression equation for this size of ingot at a significance level of 1 in 100 was found to be (H_s, cal./g.):

$$\frac{H_s}{\sqrt{t}} = 9{\cdot}38 + 0{\cdot}354\left(\frac{t}{10}\right) - 0{\cdot}0239\left(\frac{t}{10}\right)^2 - 0{\cdot}449\left(\frac{\theta}{100}\right)$$

The rate of cooling of ingots would be expected to decrease with increase of ingot size owing to a decrease in the ratio of surface area to mass. This is confirmed by data obtained from 8- and 15-ton ingots illustrated in the following table:

Ingot Weight, tons	8	15
Mass of 1-cm. thick mid-height section, g.	48,300	76,160
Perimeter of mid-height section, cm.	350	432
Mass per unit area	138	176
Mass per unit area: ratio	1	1·3
Values of K in $H_s = K\sqrt{t}$	9·76	8·20
Ratio	1·2	1

The effect of increasing initial mould temperature is to decrease the rate of heat loss, and it will be seen from the equations and from Fig. 1 that the magnitude of this effect increases with increase of ingot size.

Rate of Solidification of Ingots

The mean shell thickness in time t can be expressed by an equation:

$$S = K\left[1 - a\left(\frac{\theta}{1000}\right)\right]\sqrt{t}\ \text{cm.}$$

where K (15-ton ingots) = 3·3, a (15-ton ingots) = 1·0
K (8-ton ingots) = 2·95, a (8-ton ingots) = 0·54

The values of the temperature coefficients are very nearly the same in both the heat loss and the solidification equations, and therefore the values of H_s/S for each ingot size can be taken as being independent of initial mould temperature.

CONCLUSIONS

(1) The shortest practicable stripping time for ingots between 8 and 15 tons can be obtained from data illustrated in Fig. 2. Use of this graph will enable ingots to be charged in the hottest possible condition

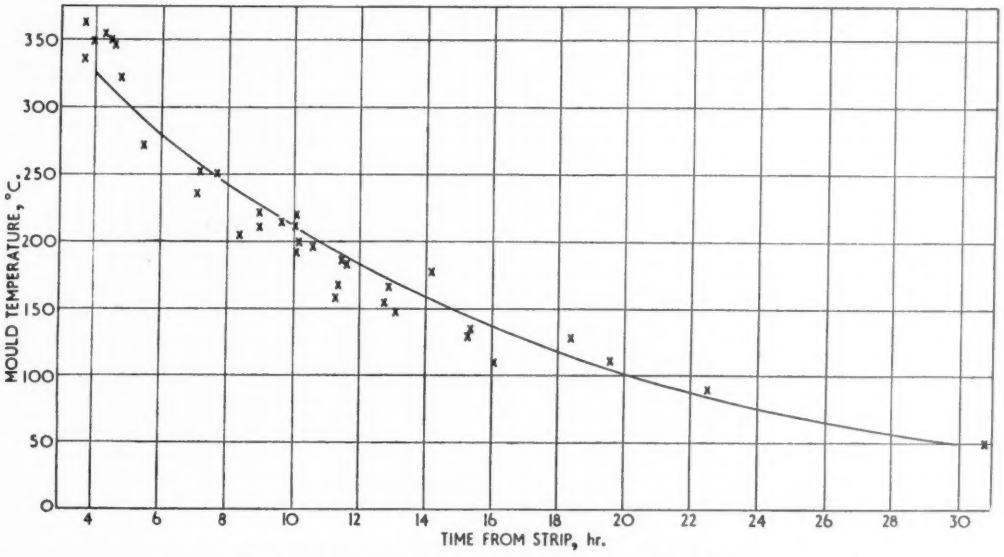

Fig. 9—Cooling of 15-ton ingot moulds after stripping

Table III

TRIALS ON 15-ton INGOTS: METHOD OF CALCULATION OF THICKNESS OF SOLIDIFIED STEEL

	Trial 5									Trial 10									Trial 13								
Initial mould temperature, ° C.	148									196									32								
Mass of steel in mid-height section, g.	76,160									76,160									77,120								
Superheat in steel above liquidus temperature, cal./g.	2·1									2·7									4·8								
Time from start of teem, min.	10	20	30	40	50	60	80	100		10	20	30	40	50	60	80	100		10	20	30	40	50	60	80	100	
Heat loss from steel, cal./g.	23·1	34·0	43·3	51·3	59·6	66·2	75·2	83·3		20·9	30·6	39·6	46·9	53·9	61·6	71·4	79·0		26·3	40·4	49·9	58·2	65·2	71·8	84·5	93·0	
Average inside surface temp. of mould θ_m, ° C.	552	598	627	651	671	686	707	717		592	619	643	663	686	704	724	733		494	547	578	602	620	635	661	695	
Instantaneous heat flux, cal./sq.cm. sec. $F_N = \frac{M}{60P}\frac{(a + 3bt + 5ct^2 - g)}{2\sqrt{t}}$*	3·75	2·99	2·64	2·38	2·17	1·95	1·51	1·01		3·55	2·85	2·52	2·28	2·08	1·87	1·44	0·95		4·24	3·30	2·87	2·57	2·31	2·06	1·56	1·03	
Outward heat flux from steel, cal./sq.cm. sec. $\sigma(\theta + 273)^4 = F_N + (\theta_m + 273)^4$	8·13	6·76	6·17	5·75	5·41	5·05	4·27	3·33		7·86	6·56	6·00	5·60	5·41	4·98	4·22	3·29		8·95	7·21	6·45	5·93	5·49	5·04	4·16	3·25	
Average steel surface temp. θ_s, ° C.	1291	1220	1187	1161	1139	1115	1058	978		1277	1209	1176	1151	1139	1110	1054	974		1329	1245	1203	1172	1144	1115	1049	971	
Thickness, cm.	7·7	11·5	15·1	18·2	21·7	24·5	27·8	29·9		6·6	9·9	13·2	15·9	18·8	22·1	25·7	27·3		8·2	13·3	17·0	20·3	23·2	25·4	31·2	33·6	
" in.	3·0	4·5	5·9	7·2	8·5	9·6	10·9	11·8		2·6	3·9	5·2	6·3	7·4	8·7	10·1	10·7		3·2	5·2	6·7	8·0	9·1	10·0	12·3	13·2	
% solidified	27·4	39·4	49·8	58·0	66·5	72·6	79·1	82·9		23·8	34·5	44·4	52·1	59·5	67·4	75·1	78·2		29·0	44·7	54·9	63·2	69·9	74·5	85·0	88·8	

* Modification to calculation of F_N

$$F_N = \frac{1}{60}\cdot\frac{M}{P}\cdot\frac{dH_s}{dt} \text{ and } H_s = \sqrt{t}\,[a + bt + ct^2 - g^{[\theta]}] \qquad \therefore \frac{dH_s}{dt} = \frac{[a + 3bt + 5ct^2 - g^{[\theta]}]}{2\sqrt{t}}$$

compatible with safe handling. This will lead to reduced fuel consumption in soaking pits, increased pit availability, and increased mould life.

These stripping times have been determined from investigations carried out on 8- and 15-ton rimming steel ingots which have shown that:

(2) For 15-ton bogie-cast bottle-top ingots, neglecting heat transfer perpendicular to the mid-height plane:

(*a*) The heat lost (H_s) after teeming can be expressed approximately by

$$H_s = 8{\cdot}20\sqrt{t}\ \text{cal./g.}\ldots(\sigma = 0{\cdot}83)$$

$$\text{or} = 0{\cdot}33\sqrt{t}\ \text{therms/ton} \quad \ldots\ldots\ (\sigma = 0{\cdot}033)$$

(*b*) The value of $H_s/\sqrt{t}$ decreases with increase of initial mould temperature (θ° C.) and over the range normally found in practice (20–200° C.) it can be more accurately expressed by:

$$\frac{H_s}{\sqrt{t}} = 9{\cdot}37\left(1{-}0{\cdot}96\,\frac{\theta}{1000}\right)$$

$\ldots H_s$, cal./g., $\sigma = 0{\cdot}67$

$$= 0{\cdot}38\left(1{-}0{\cdot}96\,\frac{\theta}{1000}\right)$$

$\ldots H_s$, therms/ton, $\sigma = 0{\cdot}027$

(*c*) $H_s/\sqrt{t}$ was also found to vary with time from start of teeming and the best-fit regression equation was found to be:

H_s, cal./g.

$$\frac{H_s}{\sqrt{t}} = 8{\cdot}10 + 0{\cdot}449\left(\frac{t}{10}\right) - 0{\cdot}0287\left(\frac{t}{10}\right)^2 - 0{\cdot}895\left(\frac{\theta}{100}\right) \quad \ldots(\sigma = 0{\cdot}51)$$

H_s, therms/ton

$$\frac{H_s}{\sqrt{t}} = 0{\cdot}325 + 0{\cdot}180\left(\frac{t}{100}\right) - 0{\cdot}115\left(\frac{t}{100}\right)^2 - 0{\cdot}036\left(\frac{\theta}{100}\right) \quad \ldots(\sigma = 0{\cdot}020)$$

(*d*) Making certain simplifying assumptions, the average thickness of solidified shell (S) is given by:

$$S = 3{\cdot}3\left(1 - \frac{\theta}{1000}\right)\sqrt{t}\ \text{cm.}$$

$$= 1{\cdot}30\left(1 - \frac{\theta}{1000}\right)\sqrt{t}\ \text{in.}$$

(*e*) The temperature of the cooling mould after stripping can be estimated by the formula:

$$\theta_m = 438 \cdot 0e^{-0 \cdot 0726t'} \ldots\ldots\ldots\ldots\ldots\ldots (\sigma = 1 \cdot 1^\circ \text{C.})$$

where t' is the time from stripping ($t' > 3$ hr.)

Thus the minimum time from start-teem to start-strip can be estimated from the time from *previous* strip to start-teem.

(3) A comparison of these results obtained from 15-ton ingots with results of work carried out on 8-ton ingots shows that increasing ingot size

(*a*) Decreases the rate of cooling owing to a decrease in the ratio of surface area to mass
(*b*) Increases the magnitude of the effect of initial mould temperature

(4) For each size of ingot, the ratio H_s/S has been found to be practically independent of initial mould temperature.

Acknowledgments

The authors wish to express their thanks to the Steel Company of Wales, Ltd., for permission to undertake the work, and to the management, staff, and operators of the melting shop, the casting bay, the stripper bay, the mould-preparation bay, engineering department, and the metallurgical department for their assistance in preparing the test mould and carrying out the trials. They also wish to thank Mr. R. Collins and Mr. R. F. Slade, who undertook a large part of the statistical calculations, Mr. T. P. Conway and Mr. R. Abbott, for their assistance in making up the equipment, and Miss I. M. Slade, for her assistance in providing the heat-protective clothing used during the trials

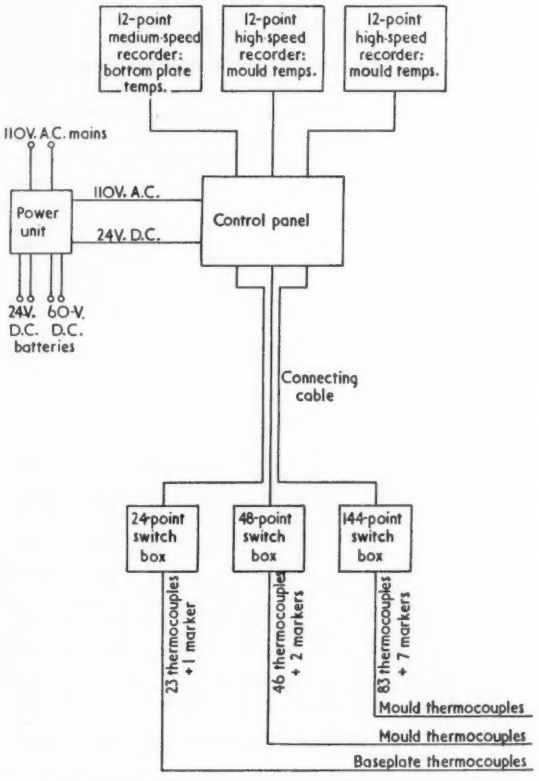

Fig. 10—Schematic arrangements of recorders, switch-boxes, and auxiliaries

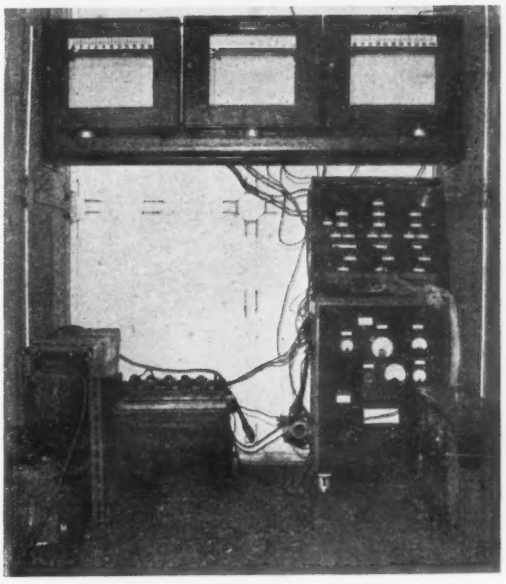

Fig. 11—Arrangement of instruments in control cabin

APPENDIX I

Instrumentation of the Trials

The experimental programme called for the continuous recording of temperatures given by 152 thermocouples in the test mould and bottom plate. The instruments used are shown schematically in Fig. 10 and illustrated in Fig. 11.

Thermocouples were made from chromel and "Red Fox" alloy and individual wires were insulated with fibreglass sleeving. Alumel, used in the previous trials, was found to become brittle and fracture, and, at the suggestion of Gray,[10] it was replaced by "Red Fox" alloy. These thermocouples proved quite satisfactory, although each batch of wire required calibrating and the millivolt output was about half that of a chromel/alumel thermocouple. Groups of wires from each thermocouple plug were sheathed in asbestos plaited tubing and at convenient points were formed into two cables from the mould and one cable from the bottom plate. These terminated in 25-pin miniature plugs, which connected directly with the three switchboxes, as shown in Fig. 2. Provision was made to identify the individual plugs by a system of "markers," which has already been described.[8, 9]

The cables containing the thermocouple wires were disconnected from the switch boxes before stripping and prevented from being damaged during stripping, both by contact with the ingot and when the mould was lowered to the ground, by attaching them to the end of a jib arm which was hinged to the side of the mould. This jib arm could be locked in position either alongside the mould or at right-angles to it, as was the case during

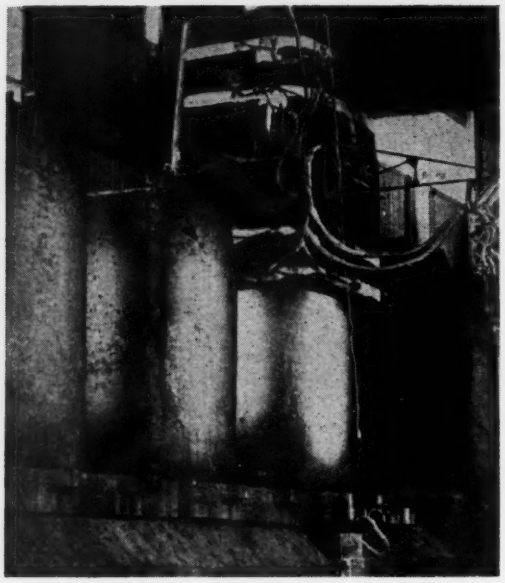

Fig. 12—Position of jib arm during stripping

stripping. The use of the jib arm during stripping is illustrated in Fig. 12.

When disconnecting the cables containing the thermocouple wires from the switchboxes it was necessary for the operators to wear protective clothing, owing to the great heat to which they were subjected. This clothing took the form of leggings, jacket, gloves, and hood made of fabric coated with aluminium foil.

The switchboxes were placed inside a heat-insulated cabinet which was bolted through anti-vibration mountings to the end of the bogie on which the test mould stood. This cabinet was protected from dust and possible splashes during teeming by an outer cabinet bolted directly on to the end of the bogie. This outer cabinet had two doors on the front which gave access to the switchbox connections.

A cable, terminating in three 25-pin miniature plugs, which was fastened along the train to the side of the bogies, served to connect the switchboxes to the control panel located in the instrument shelter at the front of the train (*see* Fig. 5). This cable also carried copper/constantan thermocouple wires which were used to determine the temperature difference between the switchbox housing and instrument cabin.

Provision was made to supply power to the instruments and the switchboxes both when the train was stationary and whilst it was being shunted from one part of the works to another.

The recorders required 110 V. A.C. at 50 cycles and the switchboxes 24 V. D.C. When the train was stationary in the casting bay or mould-preparation bay, 110-V. A.C. mains were used directly for the recording instruments, and a supply was taken via a transformer-rectifier for the switchboxes.

When the train was mobile a motor generator, operated from a 60-V. battery supply, was used to supply 110 V. A.C. at 50 cycles, and another 24-V. battery supply served for the switchboxes.

The changeover from mains to batteries was controlled by a mains switch on the control panel.

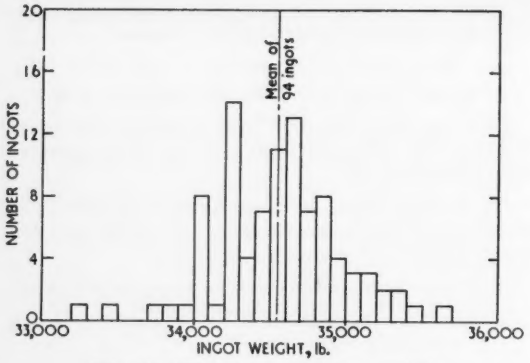

Fig. 13—Histogram of ingot weight

To allow for any variations in recorder chart speed due to variations in mains or generator frequency, a pen was used to mark the chart at 1-min. intervals. This pen was operated by a solenoid which was energized momentarily every minute when a clockwork timer closed a switch.

The recorders, batteries, power unit, and control panel were all housed in an instrument cabin on the first bogie of the train. The stand containing the power unit, with control panel above, was fastened to the floor by anti-vibration mountings. The recorders were bolted to a frame which was fixed by six anti-vibration mountings to another frame bolted across the cabin to its walls.

APPENDIX II

The Relation Between Ingot Weight and Density

Variation in ingot weight is found to occur in practice as a result of variation in the amount of steel teemed into a mould. In bottle-top moulds, upon solidification, the steel fills the mould and, if the latter is assumed to have constant volume, a variation in the mean density of steel will result.

A study was made of the weights of all 15-ton ingots in eight casts studied and the average weight found was assumed to correspond to a density of 6·83, quoted by the steel company as the mean density of rimming steel. Densities corresponding to other ingot weights were then calculated.

Figure 13 is a histogram showing the ingot weight distribution for 94 casts.

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Inhomogeneous Deformation During the Temper-Rolling of Annealed Mild Steel

By B. B. Hundy, B.Sc., Ph.D., A.I.M.

SYNOPSIS

The temper-rolling of annealed mild steel does not give an uniformly worked sheet, but instead the deformation is inhomogeneous with narrow worked and annealed regions alternating with each other along the length of the sheet. This inhomogeneity of deformation is the cause of surface corrugations at right-angles to the rolling direction inside the stretcher-strain markings in aged temper-rolled sheet and of a similar substructure arising on deep etching the steel. As the temper-rolling reduction is increased, the proportion of worked material increases and the structure is gradually broken up until, at reductions greater than about 3%, the steel sheet is worked throughout. 1176

IF AGED TEMPER-ROLLED steel sheet is polished carefully before pressing and the stretcher strains are examined, it will be seen that they are usually slightly different from those appearing when annealed sheet is pressed. The markings on rolled sheet often contain a substructure running roughly transversely to the direction of temper-rolling, while those on annealed sheet contain no such substructure. The markings were studied more closely by examining a variety of aged steel sheets, pulled so as to give stretcher-strain markings. The specimens obtained in this way were examined carefully at a low magnification on the Vickers Projection Microscope, using a modified lighting system to give the maximum contrast to any substructure present in the markings.[1]

The surface of lightly rolled specimens pulled in this way became corrugated inside the stretcher-strain markings and a typical example is shown in Fig. 1*a*; the axis of the corrugations is perpendicular to the rolling direction. This type of marking will be referred to, in this paper, as the *S*-substructure. The substructure was most pronounced at the lower reductions and, at rolling reductions greater than about 3%, the substructure was not apparent and the surface markings took the form of oblique striations at 54° to the specimen axis (Fig. 1*b*). This latter type of marking is a result of the type of yielding occurring in more heavily worked and aged material and has also been observed on stretching Al–Mg alloy sheet.[2] The result of stretching an annealed-steel specimen is shown in Fig. 2. No *S*-substructure is present. Other tests showed that the direction of testing affected the appearance of the markings. The *S*-substructure could not be seen when the specimen was cut transversely to the rolling direction; at intermediate angles of testing, the markings appeared obliquely on the specimen and grew less distinct as the angle of testing tended towards the transverse direction. The appearance of the markings seems to depend also, to some extent, on the conditions of rolling and on the steel itself. In an earlier test, a sample of 18 S.W.G. steel (obtained from a different supplier), showed a much more regular pattern when stretched after temper-rolling 1·4% (Fig. 3).

A very similar surface effect was observed when samples of these steel sheets were etched in 10–20% nitric acid to a depth of 0·005–0·010 in. Two typical examples of the substructure revealed by this treatment are shown in Fig. 4. It was found that these surface markings, called the *E*-substructure, became less distinct as the temper-rolling reduction was increased, and could not be distinguished in specimens not showing the *S*-substructure (rolled more than 3%). No *E*-substructure could be seen when annealed sheet containing stretcher-strain markings was etched in this way.

It seems most probable, therefore, that the *S*- and *E*-substructures are related and are probably both due to the same cause. It is suggested that they occur because the deformation during temper-rolling is not uniform, but occurs in narrow bands parallel to the roll axis, and these bands of worked steel are separated by other unworked bands. Therefore, according to this hypothesis, lightly-rolled steel sheet should contain alternate bands of worked and annealed material running roughly at right-angles to the rolling direction. Cold work accelerates the rate of metal dissolution so that, after prolonged etching, the unworked parts of the steel should stand out in relief from the worked

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parts. This would explain the *E*-type surface markings. Similarly, the yield stress of the worked bands will rise during strain-ageing and, on stretching, this material will not yield at the same load as the unworked material, but will stand out in relief giving rise to the *S*-substructure. The fact that no *S*-type markings are seen when the test piece is cut in the transverse direction is perhaps only to be expected; in this case the harder material can have a constraining influence on the softer parts of the sheet, preventing appreciable localized yielding of these parts.

If yielding does occur in bands in this way during light temper-rolling, it should be possible to see some markings on the surface of the sheet immediately after rolling. A highly polished sheet of deep-drawing steel was given a light reduction in the mill and was not treated in any other way before examination at a magnification of $\times$ 3·5. By very careful adjustment of the illumination some transverse markings could be detected, and an example of these is shown in Fig. 5.

Meyer and Nehl[3] etched some rolled square bars of mild steel in Fry's reagent to show the mode of deformation during rolling. Their results indicate that yielding in rolling does occur in the manner suggested, but their work was not detailed and they did not relate the type of deformation to the rolling reduction. It was decided, therefore, to roll some thick samples of mild-steel section and then etch them to show the mode of deformation in more detail. Flat samples of $\frac{3}{4}$-in. thick basic-Bessemer mild-steel plate were rolled to various reductions up to 3% on a 10-in. mill, and in each case the mill was stalled before the sample had been completely rolled, so that the rolls could be lifted apart and the sample removed. A cross-section was taken so as to reveal the mode of deformation through the arc of contact of the rolls and steel specimen. The sections were aged for 30 min. at 250° C., and were polished on emery paper down to 2/0 or 3/0 grade. They were then etched by swabbing with a mixture of 45 g. cupric chloride, 180 ml. hydrochloric acid, and 100 ml. water. The results of some of these tests are shown in Fig. 6; those regions of the steel that have yielded plastically show up dark on etching, whilst those parts that are still in the annealed condition are etched lightly. In the case of specimens given the lighter reductions, the deformation is definitely not homogeneous but occurs in bands as suggested; this non-uniformity of deformation is not confined to the initial part of the deformation zone (the arc of contact is indicated by the arrows in the photographs), but persists after the specimen has passed through this zone. Thus, the lightly rolled specimens contain regions of undeformed metal. By sectioning in a plane parallel to the specimen surface and etching, it could be shown that the regions of unworked metal extended in the transverse direction for some distance roughly parallel to the roll axis (Fig. 7).

Figure 6 shows that the amount of unworked material in the rolled specimens decreases as the rolling reduction is increased until, at a reduction of 3% or more, no unworked metal remains and the steel is worked fairly uniformly throughout. This figure also shows that the deformation is most inhomogeneous in the core of the specimen, and that there is a zone of more uniform diffuse deformation near the surface; this is probably due to the friction between the rolls and the sample.

This mode of deformation is probably associated with the sharp yield point and large yield-point elongation of annealed mild steel. If the metal had a smooth stress/strain curve, it is probable that it would be deformed fairly uniformly by even a light rolling reduction. The sharp yield point in mild steel can be removed by water-quenching from above about 700° C.,[4, 5] and some steel specimens were treated in this way before rolling. Even in those specimens given a light rolling reduction ($< 1\%$) no pronounced *S*- or *E*-type substructure could be seen (e.g. Fig. 8). Thus, it seems that the deformation during the temper-rolling of quenched mild steel is homogeneous and that, as suggested, inhomogeneous deformation during temper-rolling (and therefore the occurrence of the two substructures) is associated only with steels having a sharp yield point.

Temper-rolled steel usually has to be flattened in normal steelworks practice, and a few tests were carried out to see if this affected the degree of inhomogeneity. It was found that light roller-levelling had no noticeable effect, but that heavy roller-levelling, using a leveller with small rolls and a large intermesh, reduced the degree of inhomogeneity and the two types of substructure were less pronounced.

DISCUSSION

It is possible that this inhomogeneity of temper-rolled steel sheet may help to account for one or two observations that have been made in connection with the process of temper-rolling.

Load measurements on two experimental 4-high mills (with 7-in. and $1\frac{1}{2}$-in. dia. work rolls), have shown that the relation between roll load and the temper-rolling reduction is of the form shown in Fig. 9.[6] There is an inflection in these curves at a reduction of about 2–3%. This inflection may be associated with the rolling reduction at which the steel sheet is worked homogeneously on emerging from the roll gap, and it is significant that the roll-load/reduction curve for a material without a sharp yield point was found to be smoothly curved with no inflection at light reductions.

Previous work[7] has shown that, up to a reduction of 2–3%, temper-rolled steel sheet ages more rapidly (as shown by the return of the yield point) in the transverse direction than in the rolling direction: at higher reductions the converse applies. This finding has already been discussed in terms of the masking action of macroscopic and microscopic residual stresses, but it is perhaps significant that the changeover from one type of behaviour to the other occurs at a reduction of about 3% which, it is suggested, is the reduction at which the deformation during rolling becomes uniform. Thus, it is not impossible that the inhomogeneity of deformation in temper-rolled steel sheet may have some influence on the anisotropy of its strain-ageing behaviour.

If temper-rolled steel sheet is not uniformly worked but contains zones of unworked metal, the present

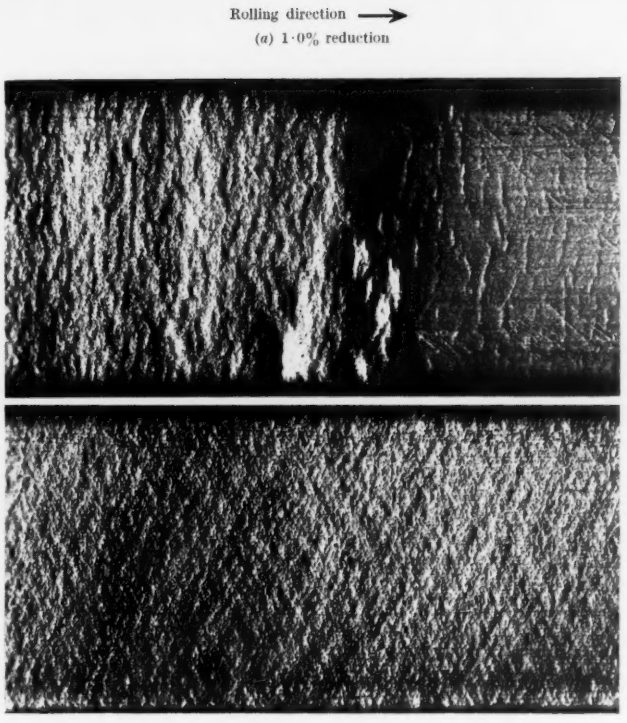

Fig. 1—Surface appearance of temper-rolled mild steel after stretching slightly in the rolling direction. Aged 12 months × 3·5

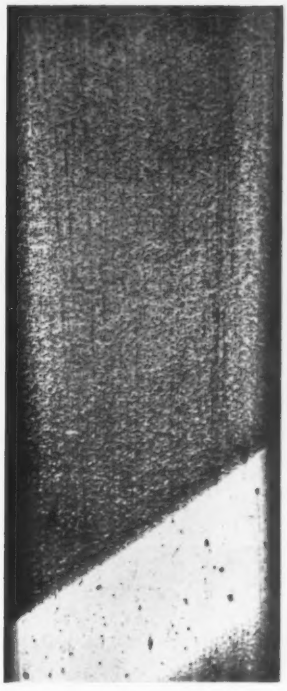

Fig. 2—Surface appearance of annealed mild steel after stretching × 3·5

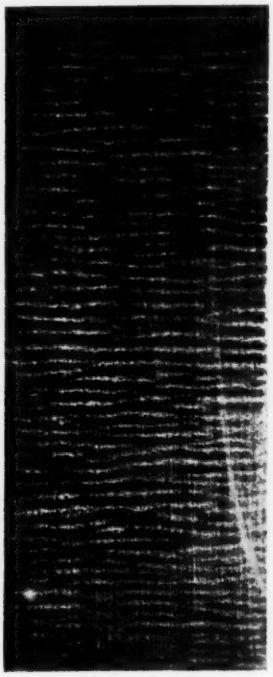

Fig. 3—Surface appearance of mild steel temper-rolled 1·4% and stretched in the rolling direction. This steel came from a different source from those in Figs. 1 and 2 and was of heavier gauge × 3·5

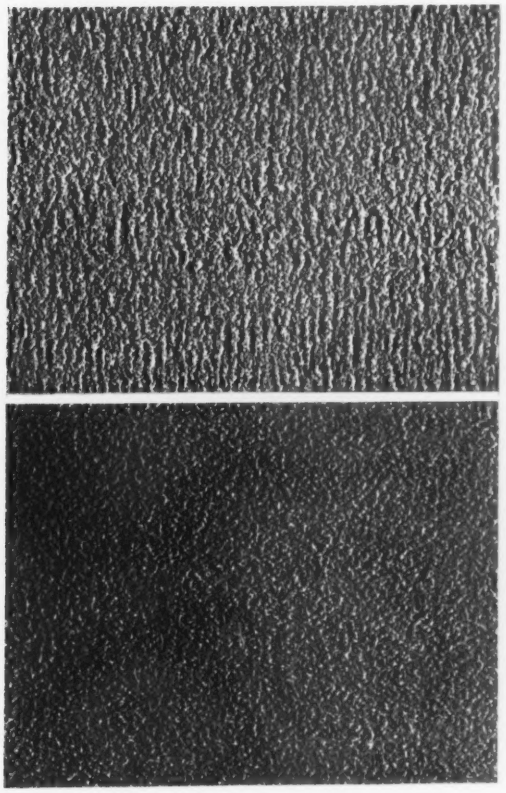

Fig. 4—The surface of temper-rolled mild steel specimens after deep-etching in nitric acid. Oblique illumination × 3·5

Rolling direction →

Fig. 5—The surface of a polished sample of mild steel after temper-rolling. Glancing illumination × 3·5

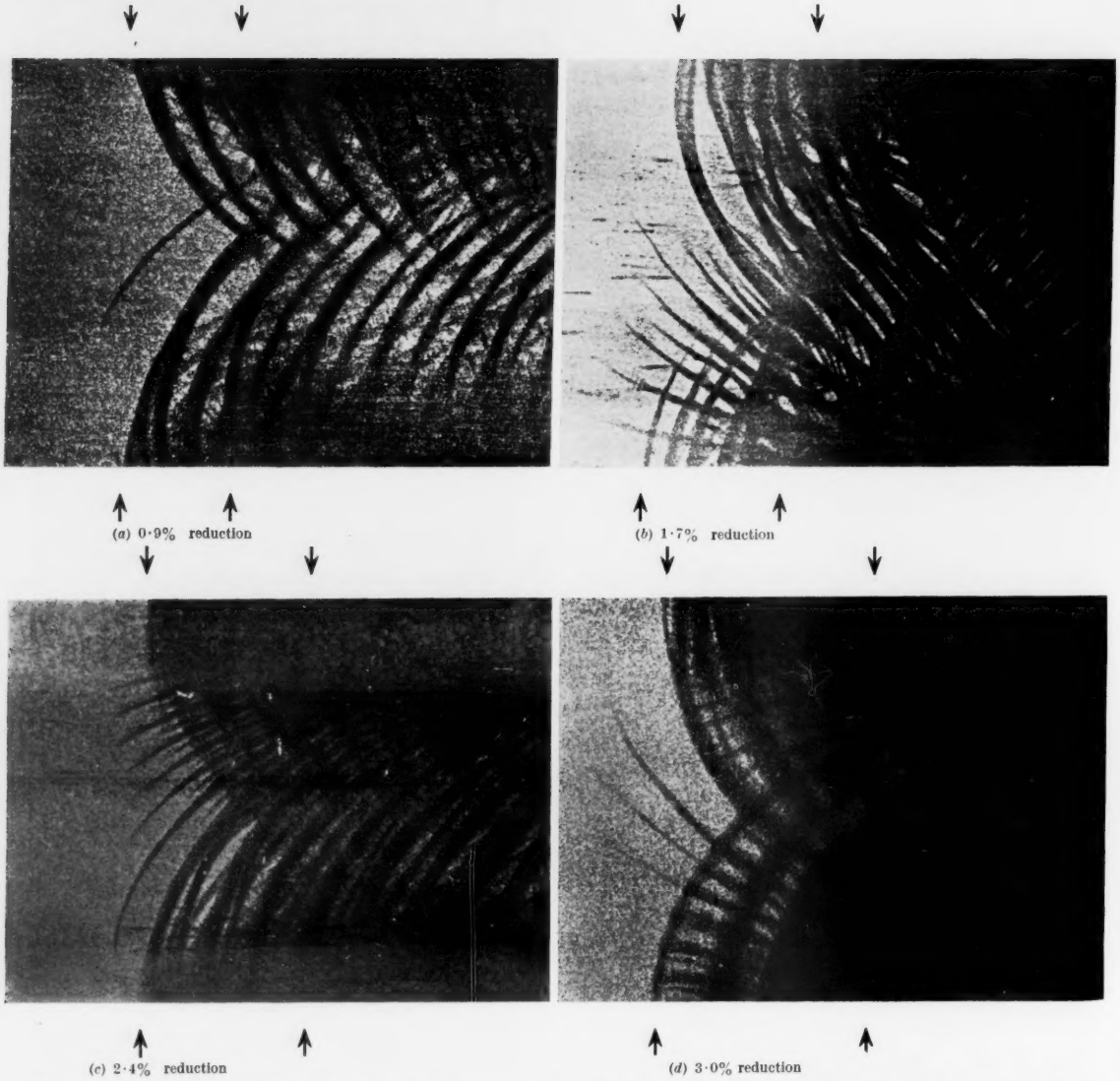

Fig. 6—Vertical sections through the arc of contact, showing the mode of deformation during the rolling of mild-steel bars. The arc of contact between the rolls and specimen is indicated by the vertical arrows. Etched in Wazau's reagent × 3·5

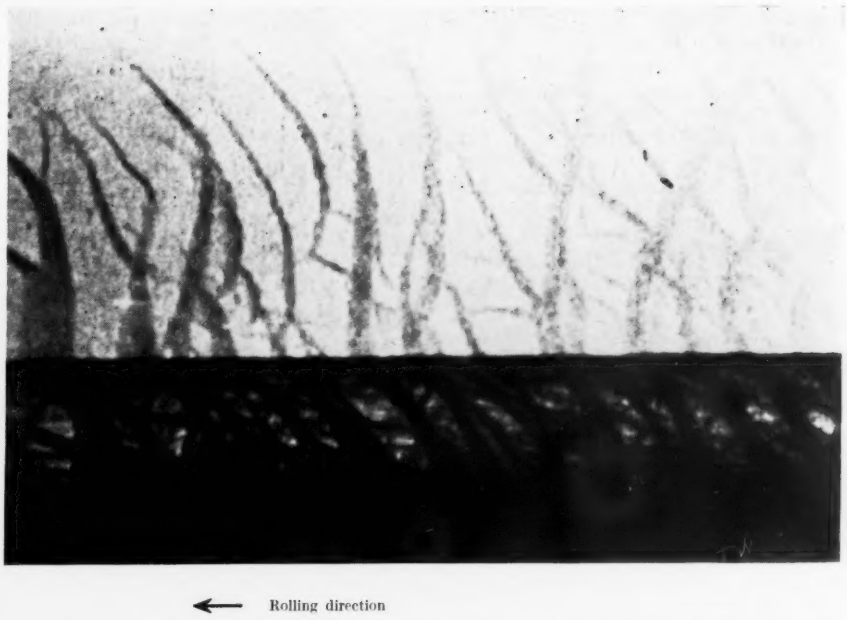

Fig. 7—Vertical and horizontal sections in mild steel given a 0·9% reduction, showing the three-dimensional mode of deformation. Etched in Wazau's reagent × 3·5

Fig. 8—Surface appearance of temper-rolled mild steel after stretching in the rolling direction. Water-quenched from 930° C. before rolling. 2·0% reduction × 3·5

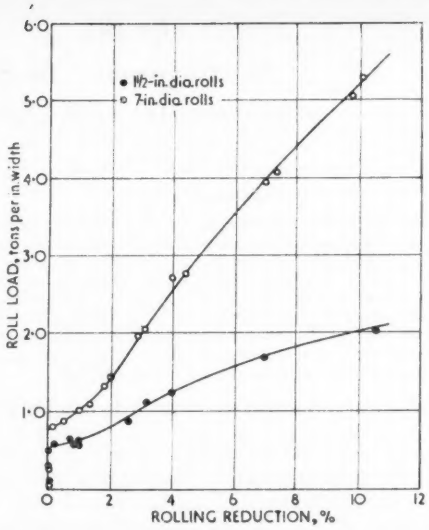

Fig. 9—The relation between the roll load and the reduction during the temper-rolling of annealed mild steel (after Huggins)

experiments can be taken as helping to confirm the effect of residual stresses in masking the yield point.[8] The unworked zones in the rolled sheet must still retain the typical yield point of annealed mild steel and one would expect them to give rise to some yield-point effect when the sheet is stretched immediately after rolling. However, it is only at very light reductions (less than 0·5%), where the proportion of unworked steel is very high, that a yield point is observed. Steel sheet, temper-rolled 1%, shows no yield point on testing but it contains unworked metal, as the above experiments have shown. The yield point of this material must be masked in some way and residual stresses seem to be the only convincing explanation.

Acknowledgments

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Ironmaking Record at Appleby-Frodingham

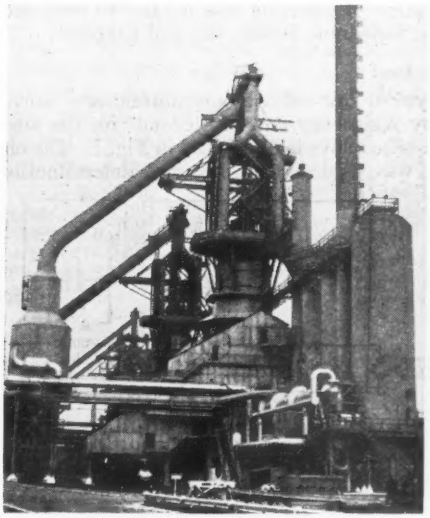
In connection with his recent paper on ' Developments in Ironmaking at Appleby-Frodingham ' (*J. Iron Steel Inst.*, 1955, vol. 181, Sept., pp. 1–16), Mr. **G. D. Elliot,** Works Manager (Iron) of the Appleby-Frodingham Steel Company, has supplied the following information about a recent performance by the *Queen Victoria* blast-furnace, during an experimental period of one week.

The furnace was burdened almost entirely with sinter, screened so as to eliminate the $-\frac{1}{2}$-in. fraction. The actual mixture used for the experiment was:

Sinter	90·7%
Northants ore	0·9%
Frodingham ore	1·9%
Scrap	1·3%
Mill scale	5·2%

During the week ending 1st October, 1955, two blowers were put into the furnace, and the operating pressure rose to 33 lb./sq. in. Details of the furnace's performance during this experimental week are:

Output	11,160 tons
Coke consumption	15·89 cwt./ton
Slag volume	25 cwt./ton
Flue dust	1·43 cwt./ton
Burden charged	50·25 cwt./ton



Spectrographic Determination of Residual Elements in Steel

By the
Spectrographic Analysis Sub-Committee of B.I.S.R.A.

SYNOPSIS

The report describes a method for the spectrographic determination of residual elements (vanadium, molybdenum, cobalt, tin, and titanium) in steel using a low-voltage intermittent-arc source unit. The effect of both silver and graphite counter electrodes was studied and it was observed that the density of the Ni and Co lines was enhanced when silver was substituted for graphite, although the overall intensity of the iron spectrum decreased. The low-voltage intermittent-arc source unit is particularly suitable for the determination of elements occurring in low concentrations. 1173

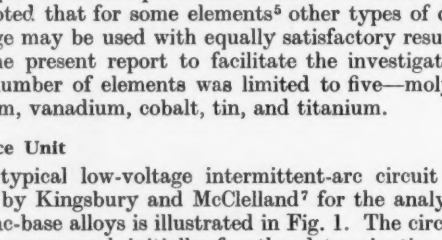
IN EARLY REPORTS dealing with the spectrographic analysis of steel,[1, 2] two types of electrical discharge have usually been used to excite the samples. When a high degree of sensitivity has been required the results have been obtained by means of the D.C. arc, but when reproducibility of results has been of prime importance the high-voltage condensed-spark discharge has been used. The latter has been particularly useful in the analysis of low-alloy steels and is used in the spectrographic method recommended by the British Standards Institution.[3, 4]

Increasing use is now being made, however, of the controlled intermittent-arc discharge. This type of source is particularly suitable for the determination of elements occurring in low concentrations, since it combines the sensitivity of the D.C. arc with an order of reproducibility usually associated with the condensed-spark discharge. It is a type of source which has already been used for the determination of trace and residual elements in steel.[5, 6] It has also proved extremely useful in the analysis of non-ferrous alloys, its successful application to the analysis of low-melting-point alloys being due to the cooling of the sample which occurs between each discharge. The low-voltage intermittent arc has also been used for the analysis of slags and refractory materials.

This report describes the application of the low-voltage intermittent arc to the determination of residual elements in steel. In some cases it may be necessary to consider the excitation conditions for a particular element separately if maximum sensitivity is required for that particular element. It should also be noted that for some elements[5] other types of discharge may be used with equally satisfactory results. In the present report to facilitate the investigation the number of elements was limited to five—molybdenum, vanadium, cobalt, tin, and titanium.

Source Unit

A typical low-voltage intermittent-arc circuit as used by Kingsbury and McClelland[7] for the analysis of zinc-base alloys is illustrated in Fig. 1. The circuit shown was used initially for the determination of aluminium in refractory materials. It consists essentially of a high-capacity low-voltage condenser (*C*3) which is discharged across the analysis gap (*G*2) by means of a triggering spark developed in a high-voltage condensed-spark circuit (*T*1, *C*1, *L*1, and *G*1). The low-voltage circuit may be powered from either an A.C. or a D.C. mains supply. A resistance (*R*) controls the current through the circuit when the analysis gap is closed and this current value is quoted when specifying excitation conditions. The chokes *L*3 and *L*4 and the condenser *C*2 prevent the high-frequency currents feeding back into the mains. The discharge of *C*3 causes the emission of spectrum radiations from the sample. The high-voltage circuit is coupled to the low-voltage side by the Tesla coil (*T*2). The width of the control gap *G*1 can be adjusted so that one discharge of *C*1 occurs per half-cycle of the A.C. mains supply. Consequently, the frequency of the triggering spark (and therefore of the discharge of the condenser *C*3) can be regulated.



*T*1	High-voltage transformer	*C*3	50 mF. low voltage
*T*2	High-frequency transformer	*L*3, *L*4	H.F. chokes
*G*1	Control gap	*R*	Variable resistance
*G*2	Analysis gap	*A*1, *A*2	A.C. ammeters
*C*1, *C*2	0·005 mF. high voltage	*S*	Double pole switch

Fig. 1—Circuit diagram of intermittent A.C. arc

Source units of this type were available in each of the laboratories participating in the determination of the residual elements in steel. These units, however, differed in some details of their construction, and it was for this reason that it was not found possible to formulate a recommended method as had been done for the analysis of low-alloy steels.

Standards

Through the courtesy of the United Steel Com-

Paper MG/D/7/55 of the Spectrographic Analysis Sub-Committee of the Metallurgy (General) Division of B.I.S.R.A., received 15th June, 1955.

This work has been carried out by a study group under the direction of the Sub-Committee, whose composition at 31st December, 1954, was: Mr. J. H. Oldfield (*Chairman*), Admiralty Materials Laboratory; Mr. A. Argyle, B.C.I.R.A.; Mr. P. T. Beale (replaced Mr. W. Ramsden 30.9.54), B.N.F.M.R.A.; Mr. K. M. Bills, Mond Nickel Co., Ltd.; Mr. H. J. Dothie, Government Laboratory; Mr. H. Kaye, David Brown Foundries Ltd.; Mr. M. Z. de Lippa, Consett Iron Co., Ltd.; Mr. S. Muir, Stewarts and Lloyds Ltd.; Mr. W. T. L. Neal, N.P.L.; Mr. D. F. Sermin, Samuel Osborn and Co., Ltd.; Mr. H. T. Shirley, Brown-Firth Research Laboratories; Mr. W. S. Sykes, Steel Peech and Tozer; and Mr. R. H. Tyas, B.I.S.R.A. The Chairman, Mr. Bills, Mr. Dothie, Mr. Sermin, and Mr. Tyas comprised the study group. Acknowledgments are also due to Mr. K. Speight (B.I.S.R.A.), who acted as Secretary to the group, and to Mr. K. Dixon (Wm. Jessop and Sons, Ltd.) and Mr. G. L. Mason (United Steel Companies Ltd.), who co-operated in the work until leaving their respective organizations.

Table I—COMPOSITION OF STANDARDS, %

Sample	Mn	Si	Ni	Cr	Mo	V	Co	Ti	Sn	W	Cu	Al
SG 6259	0·117	0·107	0·095	0·185	0·105	0·060	0·085	0·055	0·067	0·110	0·130	0·054
SG 6260	0·117	0·152	0·150	0·110	0·115	0·072	0·035	0·018	0·032	0·055	0·060	0·013
SG 6261	0·177	0·237	0·190	0·140	0·165	0·120	0·021	0·013	0·023	0·015	0·020	0·025
SG 6262	0·072	0·010	0·010	0·021	0·032	0·014	0·220	0·003	0·205	0·495	0·240	0·023
SG 6263	0·047	0·010	0·060	0·028	0·031	0·018	0·130	0·005	0·100	0·300	0·175	0·008

Table II—OPERATING CONDITIONS

Laboratory	A	B	C	D
Closed-circuit current	1·8	1·8	3·0	3·0
Plate calibration	Yes	Yes	No	Yes
Log-scale graphs	Yes	Yes	Yes	Yes
Plate	B 10	B 10	B 10	B 10
Development time, Developer, Temperature	As specified in B.S. 1121B: 1953			
Pre-spark time	None	None	None	None
Counter electrode *A*	Silver	Silver	Silver	Silver
" " *B*	Graphite	Graphite	Graphite	Graphite
Exposure time *A*	2 of 45 sec.	1 of 60 sec.	2 of 20 sec.	2 of 30 sec.
" " *B*		1 of 60 sec.	2 of 20 sec.	2 of 20 sec.
Electrode size	80° cone, ¼ in. dia.	80° cone, ¼ in. dia.	80° cone, ¼ in. dia.	80° cone, ¼ in. dia.
Source–slit distance, cm.	38	38	38	35
Analysis gap distance, mm.	2	2	2	2
Wave-band setting, Å.	4400–2700	4400–2700	4400–2700	4400–2700

panies' laboratories a number of standards became available for the construction of working curves. The standards were in the form of 1-in. square section rolled bar and had the composition shown in Table I.

Exposure Conditions

Experience indicated that it would be profitable to study the effect of using both graphite and silver counter electrodes and both A.C. and D.C. intermittent-arc discharges. Preliminary tests were made on sample *SG* 6259 (Table I). It was observed that for some elements there was a marked change in sensitivity when silver electrodes were substituted for graphite. In particular, the density of the nickel and the cobalt lines was considerably enhanced, although the overall intensity of the iron spectrum decreased.

No marked improvement was found when the D.C. intermittent arc was used instead of the A.C. arc, and there was also a loss in overall sensitivity.

It was not possible to formulate a list of excitation conditions which could be generally applied by the participating laboratories, but a common procedure was followed where possible, and the conditions used in each laboratory are listed in Table II.

The sample *SG* 6259 (Table I) was selected for reproducibility tests, 30 exposures being made on a minimum of three plates. Working curves were prepared by plotting log ($RI_{element}/RI_{iron}$) against log percentage concentration, the characteristic curve of the photographic emulsion being obtained by the method of homologous iron lines described in the recommended method for the analysis of low-alloy steels.[4] The iron lines with approximate relative intensities are given in Table III. Smooth working curves were obtained. A survey of the results is given in Table IV.

It was observed that in general the behaviour of the discharge was more erratic when silver electrodes were used, possibly owing to the greater tendency for the formation within the area affected by the discharge of small molten globules on which the discharge tended to locate itself. It also seemed probable that more elements could be satisfactorily determined with one set of excitation conditions when graphite was used as the counter electrode material. Further tests were therefore made using graphite electrodes. The tests were carried out in laboratory *C*. Samples *SG* 6260 and *SG* 6262 (Table I) and two additional samples were used. The latter were introduced because provisional spectrographic analysis had indicated that they would extend the concentration range studied.

The circuit diagram of the source unit used is shown in Fig. 2. Instead of the Tesla coil used in the previous circuit (Fig. 1) an auto-transformer is used to couple the triggering to the low-voltage circuit. A resistance *R*2 located on the discharge side of the main condenser *C*3 enables the rate of discharge of the condenser to be controlled and this affords a means of studying the effect of a wide range of excitation conditions. The conditions finally selected were:

Waveband setting	2700Å. left end
Counter electrode	5-mm. graphite rod, 80° cone
Analysis gap	2 mm.
Capacity (*C*3)	60 μF.
Resistance (*R*2)	11 Ω

Table III—IRON LINES

Iron Spark Line	Relative Intensity
2783·696	8·02
2831·562	4·62
2793·888	1·40
2828·634	1·05
2799·286	1·00
2827·434	0·44
2819·333	0·19
2812·493	0·16

Resistance (*R*3)	Adjusted to give 4·5 A. at ammeter *A*1
Exposure time	2 × 25 sec.
Photographic plate	Kodak B 10
Plate processing, etc.	As Table II

About 40 exposures were made on each sample, spectrograms being recorded on seven plates. The results are shown in Table V.

Conclusions

The reproducibility obtained indicates that the intermittent arc discharge may be usefully applied to the determination of residual elements in steel. Under the exposure conditions used, only one tin line is suitable for measurement on the densitometer. Better reproducibility might be obtained if the determination of tin alone were considered, and the exposure conditions modified to suit this element only. It has already been pointed out that in general these remarks might apply to most elements, and the development of a composite method to determine a large number of elements may entail accepting a lower degree of reproducibility for some of them than could be obtained if they were considered singly. Similarly, the lower limits of detection may also be affected.

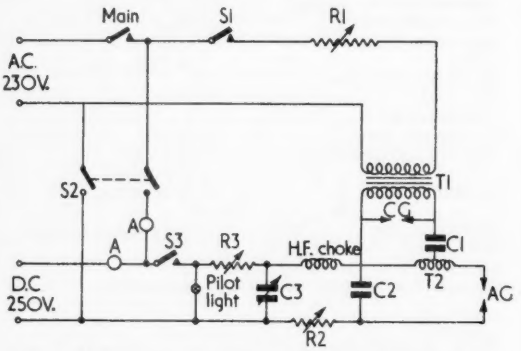
Table IV—SURVEY OF RESULTS

Lab.	Spectrographic (Average), %	Range	Coeff. of Variation		Line-Pair Wavelength, Å.
			Graphite	Silver	
Vanadium (Chem. 0·060%)					
A	0·059	0·054–0·060	3·8	3·0	3102·3
					3119·5
B	0·062	0·060–0·065	2·5	5·5	,,
C	0·060	0·054–0·063	4·0	14·0	,,
D	0·066	0·060–0·074	4·1	5·0	,,
Molybdenum (Chem. 0·106%)					
A	0·101	0·097–0·122	6·2	5·9	3170·3
					3175·5
B	0·128	0·113–0·137	6·5	7·4	,,
C	0·117	0·108–0·129	5·2	6·3	3170·3
					3167·9
D	0·104	0·094–0·114	6·15	8·6	3170·3
					3175·5
Cobalt (Chem. 0·085%)					
A	0·093	0·088–0·105	6·9	4·4	3502
					3485
B	0·086	0·083–0·092	3·7	5·0	,,
C	0·083	0·079–0·086	2·4	4·0	3453·5
					3458
D	0·094	0·088–0·100	5·7	3·6	3453·5
					3459·9
Tin (Chem. 0·067%)					
A	0·066	0·055–0·081	10·0	8·0	3175·0
					3175·5
B	0·063	0·055–0·080	11·3	8·2	,,
C	0·068	0·050–0·090		13·0	,,
D	0·069	0·055–0·100	13·7	16·2	,,
Titanium (Chem. 0·055%)					
A	0·050	0·045–0·055	5·7	7·8	3349·4
					3355·2
B	0·060	0·056–0·070	6·5	6·5	3372·8
					3372·3
C	0·053	0·048–0·058	5·6	7·1	3088·03
					3077·17
D	0·049	0·043–0·060	9·8	7·3	3349·4
					3355·2

Table V

RESULTS OF FURTHER TESTS USING GRAPHITE

Element	Chemical, %	Spectrographic, %	Coeff. of Variation	Line Pair Wavelength, Å.
Vanadium	0·072	0·069	6·0	3102·3/3111·7
	0·014	0·014	5·7	
Molybdenum	0·115	0·105	2·0	2775·4/2770·7
	0·032	0·032	6·7	
Cobalt	0·035	0·042	4·0	3044/3060·5
	0·22	0·23	7·0	
Tin	0·032	0·032	10·0	3175/3176·3
	...	...	...	



R1 0–1200 Ω
R2 0–25 Ω
R3 0–100 Ω
S1 Spark switch
S2 Changeover A.C. to D.C. switch
S3 Arc switch
C1 0·0015 mF. high voltage
C2 0·002 mF. high voltage
C3 60 μF low voltage
T1 High-voltage transformer
T2 High-frequency auto-transformer
CG Control gap
AG Analysis gap

Fig. 2—Intermittent low-voltage A.C./D.C. arc circuit

The construction of source units to a standard design would permit the formulation of a recommended method. Since, however, the study of sample excitation is still being energetically pursued and radical changes might occur in methods of excitation, it is unlikely that individual laboratories will be prepared to discard source units already effectively coping with their own especial problems in order to construct units conforming to some uniform design. In these circumstances, methods of specifying excitation conditions without reference to electrical parameters may have to be sought. These may involve a more direct approach to conditions within the analysis gap itself. In this respect it may be possible to refer to the intensity ratio of two non-homologous iron lines as specifying 'excitation conditions.'

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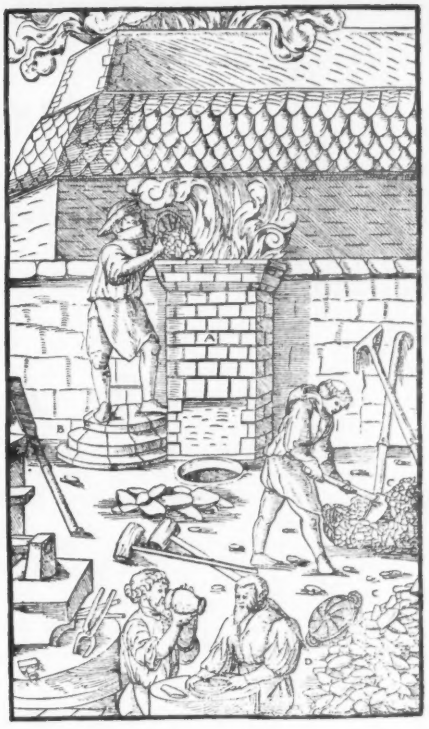
Georgius Agricola

(25th March, 1490—21st November, 1555)

By H. R. Schubert



Iron smelting in an early type of charcoal furnace
(from the first Latin edition of "*De re Metallica*", 1556)

GEORGIUS AGRICOLA—few people today would know who he was, but, at the time of his death four hundred years ago and for long after, he was known as 'the lantern of Germany' to his many admirers on the Continent and in England, one of whom was William Cecil, Lord Burghley, the trusted Chancellor and leading statesman of Elizabeth I.

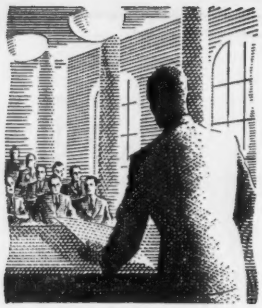
Agricola was born at Glachau in German Saxony on 25th March, 1490. On completing his academic training he became a physician, first at Joachimsthal and from 1530 at Chemnitz in Saxony, where he was appointed the town's physician (Stadtphysikus) or, to use the contemporary term, medical officer of the borough. He was also mayor of the town on several occasions, and the Prince-Elector of Saxony appointed him his historiographer.

But despite this obviously successful career, Agricola's public position was not unassailed. Animosity against him arose from his adherence to the Catholic faith, to which he remained true throughout his life; this was resented by the almost completely Protestant population of Saxony, and made his life a lonely one. It was only the international fame he had acquired which saved him from more serious trouble.

Agricola's celebrity was not in recognition of his medical skill or his activities in public life, but rested solely upon his achievements in a field which originally lay outside his training and his profession. It was his research work in mineralogical and metallurgical subjects that gained him the high reputation he enjoyed in his later days, together with the title of 'the father of mineralogy' by which he is still known to the present day. His interest in mineralogy was intensified when he was working as a physician at Joachimsthal in the mountains between Saxony and modern Czechoslovakia. In those days Joachimsthal was a centre of silver mining, known all over Europe. The rich yield of the mines gave great wealth to all social grades, from the Prince-Elector to the miners, whose opulence and independence became a source of great concern to the clergy of the district. The town gave its name to a monetary unit, the '*joachimsthaler*,' abbreviated to '*thaler*,' from which the American dollar ('*daler*' in Low German) derived its name. At Joachimsthal Agricola wrote his first book '*Bermannus, sive de re metallica*,' a treatise in the form of a dialogue published in 1528. This was the only work published in his lifetime. His major work, '*De re metallica libri XII*,' which was furnished with many illustrations, was not published until six years after his death.

Agricola was a celebrity of world-wide reputation. Erasmus of Rotterdam and Philipp Melanchthon, Luther's friend and collaborator in the development of the German Reformation, regarded him as one of the most erudite and illustrious personalities of the age. Agricola's name has a special significance for the English iron industry, since it was owing to his high reputation that one of his disciples was invited to England to erect the first wire mill in the country (i.e. a wireworks operated by mechanical power derived from water wheels instead of by manual power). This works, built at Tintern in Monmouthshire in 1566 and 1567, laid the foundations of the mechanized wire industry of the whole country. The man responsible for its erection was Christoph Schütz, a native of Saxony and a member of a Chemnitz family which had played an important part in the German copper and brass industries and in mining. The chief promoter of the scheme, without whose persistence the new enterprise would have failed, was William Humfrey, Assay Master at the Royal Mint in London. In his lengthy correspondence with Burghley, Humfrey extolled the qualities of Schütz, whom he called a '*jewel all Germany has not his like, by report of his master and bringer up who is called the lanterne of Germany as touching mineral and metallyne affayres.*' This master was Georgius Agricola, the quatercentenary of whose death is being commemorated this year.

Manuscript received 17th October, 1955.
Dr. Schubert is Historical Investigator to The Iron and Steel Institute.



DISCUSSION ON PAPERS

Discussion at Meetings · Written Contributions

AUTUMN GENERAL MEETING, 1954

The AUTUMN GENERAL MEETING of THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 17th and 18th November, 1954, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, the Hon. R. G. LYTTELTON, was in the Chair.

Morning and afternoon sessions were held on both days, and a report of one of the sessions was printed in the October issue; the remainder of the discussions are given below.

DISCUSSION ON THE WORKING OF STEEL

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parentheses):

"Effect of Cold Work on the $\gamma \rightarrow \alpha$ Transformation in Some Fe–Ni–Cr Alloys," *by B. Cina* (1954, vol. 177, Aug., pp. 406–422).

"The Strain Ageing of Mild Steel. A Critical Investigation of the Ageing of Mild-Steel Strip after Temper-Rolling," *by B. Jones and R. A. Owen-Barnett* (1954, vol. 177, June, pp. 209–220).

"Accelerated Strain Ageing of Mild Steel," *by B. B. Hundy* (1954, vol. 178, Sept., pp. 34–38).

"Elimination of Stretcher Strains in Mild-Steel Pressings," *by B. B. Hundy* (1954, vol. 178, Oct., pp. 127–138).

"Yield-Stress/Strain Curves and Values of Mean Yield Stress of Some Commonly Rolled Materials," *by R. B. Sims* (1954, vol. 177, Aug., pp. 393–399).

Dr. **B. Cina** (Brown-Firth Research Laboratories), Mr. **R. A. Owen-Barnett** (Whitehead Iron and Steel Co., Ltd.), and Dr. **B. B. Hundy** (B.I.S.R.A.) presented their papers. Mr. **R. B. Sims** (Davy and United Engineering Co., Ltd.) was unable to be present, and his paper was taken as read.

Dr. **T. P. Hoar** (Cambridge University): The paper by Dr. Cina forms a further extension of the valuable and elegant work that has come from the Brown-Firth Laboratories and the University of Sheffield during the last few years on the very complex 18/8-type alloy steels. To me, the most interesting thing in this paper is the transformation $\gamma \rightarrow \alpha$. Dr. Cina has very clearly demonstrated that in ordinary cold work by compression of an 18/8-type steel (e.g. in fabrication processes and particularly in any attempt at cold rolling) the strain hardening is very largely (*see* Fig. 20 of the paper) an inherent property of the austenite itself, rather than, as is sometimes thought, purely a consequence of the martensitic transformation.

In Fig. 20 Dr. Cina shows that the 25/12 Cr–Ni alloy strain-hardens very considerably although it does not form any martensite, and that even the 18/8 alloy strain-hardens only about 60% more than the 25/12 alloy, the extra 60% being due to the formation of the martensitic material.

Figures 10 and 11 show some results for the isothermal formation at room temperature of the martensitic or α_2 phase. Until fairly recently, the $\gamma \rightarrow \alpha$ martensitic change was thought to occur always with explosive rapidity. Quite recently, however, a number of workers in the U.S.A., Dr. Bowen and myself[1] at Cambridge, and now Dr. Cina, have shown that martensite formation can take place over a considerable lapse of time. Figures 10 and 11 in the paper show the formation of α_2 from γ taking place more or less to completion in about 30 mins. Figure *A* shows a very similar curve for the increase in α_2 ferrite, on standing at room temperature, in an 18/8/3/1 Cr–Ni–Mo–Ti commercial alloy. The interesting difference from Dr. Cina's curves is the time scale: our transformation was complete in about 24 hr. rather than 30 min. In other alloys, slightly differently heat-treated, similar transformations took place over a matter of days, weeks, or even months.

Thus, it is now evident that the martensitic change can be either of explosive rapidity or very slow; many of the discussions of the mechanism of that change will consequently have to be reconsidered. Broadly, one may suppose that the micro-stresses and strains in the austenite grains are affected by chance thermal fluctuations, so that the mechanical threshold for the change is reached every now and then at small regions.

Martensitic change after working has sometimes been called a "strain-induced" diffusionless change; should it not be regarded less as *induced by strain* than as

inhibited by stress? It may well be that compressional stress round the austenitic grains tends to prevent them from transforming to martensite unless it is altered or relieved, for example by cold working or by removing the austenite grains entirely from the matrix. In further experiments,[2] Dr. Bowen and I heat-treated an 18/8/3/1 Cr–Ni–Mo–Ti steel to give nothing but austenite and σ, both of which are non-magnetic; we selectively attacked this structure anodically under conditions such that σ was dissolved and a residue was left. This residue was strongly magnetic, the austenite having gone over appreciably to α_2. In this case it seems certain that it was the release of the stresses on the austenite grains rather than the production of strain that allowed them to undergo the martensitic transformation.

Mr. **A. J. K. Honeyman** (Steel Company of Wales Ltd.): The papers dealing with the strain-ageing of mild steel are very timely, because probably the biggest problem which sheet manufacturers and press shops have to face arises from stretcher-strains and ageing in mild steel. Steel is in its most ductile state in the cold-reduced and annealed condition, but, as Dr. Hundy says, unfortunately it has a very large yield-point elongation, and therefore the only practical method of removing this is by skin passing—i.e. by cold rolling from ¾% to 1¼%. If it is less than ¾% the whole of the yield-point elongation will not be removed; if the reduction is more than, say, 1½%, however, it will certainly remove the yield-point elongation but, as Dr. Hundy points out, it may reduce the ductility beyond the point which can be tolerated in the press shop.

The author has discussed this problem very thoroughly and has put forward several useful ideas for practical consideration. His proposal on p. 133, where he states "It seems, therefore, that there is scope for a cheap efficient machine, probably based on the leveller principle, which could be used in the press shops to process annealed steel sheet so as to prevent stretcher straining during pressing," sounds very good, but it bristles with technical and economic difficulties.

On p. 137 he states that "there is an optimum combination of temper rolling and roller levelling that will give the maximum resistance to the return of the yield point (and therefore to stretcher straining), together with the maximum ductility." He goes on to say "This combination, however, will probably have to be determined separately for each particular temper mill under consideration." That suggestion certainly deserves a very thorough follow-up. Unfortunately, there are some snags. In the case of sheet skin passing it is fairly simple, and generally speaking there is little trouble with sheet skin-pass material. Unfortunately, sheet skin-passing is not very satisfactory commercially, because the rate of output is rather low, and most sheets are now coil skin-passed. During that process the difficulty is to measure and control the amount of cold work which occurs. For example, it is necessary to begin by decoiling and then follow with a tension skin-passing, more tension coiling, decoiling, and then the final process, so that the final state of the steel so far as cold work is concerned is very difficult to estimate.

We have carried out some experiments to find out what difference there was between the rate of return of yield point and of ageing between the steel immediately after skin passing and after the final processing. So far our results have been erratic, illustrating the point which I have just made. Dr. Jones and Mr. Owen-Barnett say in their paper (p. 210) that "Differences are found in the ageing of steel strip rolled from similar casts of O.H. steel and even of parts of the same ingot." Discussing the Cottrell–Bilby theory, Dr. Hundy says, on p. 128, "Provided that there is no large difference in the degree of cold work, this theory predicts that strain ageing should only be governed by the time and temperature of ageing and by the amount of carbon and nitrogen in solution, and should not be affected by the method of plastic deformation." He has shown that the yield point is affected by the plastic deformation, but his Fig. 6 tends to indicate that the other factors are independent of that and of any other factor.

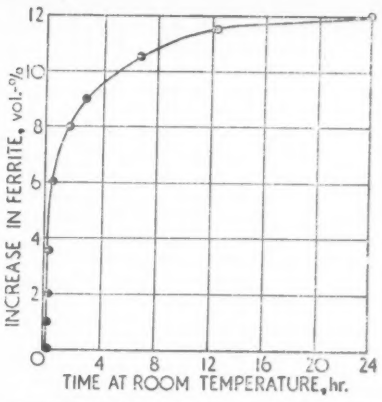


Fig. A—Increase of ferrite α_2 on ageing at room temperature; 18/8/3/1 Cr–Ni–Mo–Ti steel, heated at 800° C. for 118 hr. and W.Q. (Bowen and Hoar[1])

He does not mean that there are not other, non-mechanical factors which affect the rate of strain ageing. There are many other factors which do affect it (e.g. grain size). It is well known that fine grain size increases the rate of strain ageing, whilst a coarse grain size has the opposite effect. Unfortunately, coarse grain size is accompanied by difficulty in pressing, and so that method cannot be applied. What is good for one thing often upsets something else, so that it is always necessary to compromise. We have also found that a high sulphur content seems to accelerate the rate of strain ageing, as also does the presence of inclusions. Possibly it is not the inclusions themselves which cause the increased rate of ageing but some factor in the steelmaking which is indicated by the presence of inclusions. A great deal of work is required on the effect of the various processes and temperatures to which the metal is subjected.

Two papers have been presented which provide very useful data for the works on accelerated strain ageing, but there are several points of considerable disagreement. For example, Dr. Hundy's Table II does not agree at all with the table on p. 217 of the paper by Dr. Jones and Mr. Owen-Barnett, and there are other differences. According to Dr. Hundy's work, strain-ageing is complete in a comparatively short time (8–12 weeks), whereas Dr. Jones and Mr. Owen-Barnett report ageing proceeding for three years at least.

The results in Table II of the paper by Dr. Jones and Mr. Owen-Barnett, showing the extraordinary effect of the higher temperatures of accelerated strain ageing in giving a particularly high yield-point/elongation ratio, are explained on p. 219 by the following: "High values of yield and tensile strength are obtained on artificial ageing, owing to a rapid rate of migration of carbon and nitrogen atoms to complete the formation of carbides and nitrides. These effects are assisted by a reduction in macroscopic residual stresses, which, being noticeably retained in temper-rolled steel on ageing at room temperature, delay the rate of ageing." The authors refer there to a paper by Wishart; I have examined this paper but cannot find anything there which shows that

the residual stresses are still present after natural ageing and are not present after high-temperature ageing. Have the authors any evidence on this point? Work needs to be carried out on creep, strain ageing, and brittle fracture simultaneously, because fundamentally they represent the same phenomenon.

Two methods have been suggested by the authors to counteract the troubles experienced in the steelworks and in press shops—control of cold working and cold storage. There is no doubt that the press shops could do something by means of cold storage to solve the problem. There are two other methods. One, which is not practicable, is to remove the dislocations. The other is to create a fashion for roofs and bonnet tops showing stretcher-strains; after all, they are very pretty!

Dr. **B. Jones** (Whitehead Iron and Steel Co., Ltd.): In Dr. Hundy's paper on the accelerated strain-ageing of steel, a simple equation has been obtained based on the dislocation theory and it has been assumed that all strain-ageing phenomena are governed by this theory.

The equation gives the equivalent time of ageing at elevated temperatures and at room temperature, and the results given in Table II will serve as a most useful guide for rapid and convenient ageing tests, particularly at 100° C. The calculated ageing times at 50° and 75° C., temperatures used in our paper, agree in general with the results obtained for ageing times up to 6 months.

In contrast with the results given by Dr. Hundy we have found differences in the rate of ageing in steels strained in different ways, as steels strained in tension age rapidly in the early stages and attain the fully-aged condition at room temperature in 3–4 months, whereas temper-rolled steels are not fully aged even after 5 years of storage, although the rate of ageing is considerably retarded after one year. These differences are not allowed for in the formula, whilst for ageing periods longer than about 3 months it gives excessive times at elevated temperatures.

In his second paper, on the elimination of stretcher-strains in mild-steel pressings, Dr. Hundy has shown clearly in Fig. 3 that residual stresses induced by temper-rolling and roller levelling are of a different order, and the correlation of residual stresses with the ageing characteristics of steels after stretching, roller levelling, and temper rolling is of great interest.

Does the author consider the method used to determine the distribution of residual stresses in the steels (by stopping off one side of the sheet and etching away layers of the other side with acid) to be accurate or an approximation, and could the stress patterns be confirmed by X-ray methods? I assume that the residual-stress patterns illustrated in Fig. 3 were determined soon after straining, but has the author found that the patterns change after ageing the steels for 3 months, or after artificial ageing?

Improvements are apparently being made in roller-levelling machines, but at the moment these machines are not so efficient as temper mills for the removal of large yield-point elongations in mild-steel strip. I am not sure whether an extra charge should not be made for residual stresses imparted by temper rolling, which have been shown to be so beneficial!

The extra-deep-drawing quality steel mentioned on p. 129 had a grain size of 7 on the A.S.T.M. scale. Was the steel in the sub-critically annealed condition before temper rolling, as a tensile strain of only 4–5% removed the yield point; this amount of strain appears to be on the low side for a steel with a fine grain.

Dr. Edwards, an expert on this subject, strained mild steel by 6% to remove the yield point, whilst others used a strain of 7½% and 10% for this purpose.

Although it has been shown that a light temper rolling or 'skin pass' imparts a low level of residual stresses, the steel will resist ageing for a reasonable time if stored in a cool environment. On the other hand, there is a demand for a comparatively heavy degree of re-rolling for steel strip for special applications. Such steels supplied as '¼ hard,' '½ hard,' and even '¾ hard' fortunately are fairly resistant to strain-ageing.

The statement on p. 131 that "the rate of ageing is approximately independent of the method of working" is rather surprising, in spite of Figs. 6 and 7, because we have found that temper-rolled steel is much more resistant to natural ageing as judged by changes in yield strength, ultimate stress, hardness, and ductility, as well as by the return of the yield-point elongation, when compared with tensile-strained steel. The claim that the changes of these physical properties during ageing are unaffected by the method of removal of the yield point requires possibly some further explanation, although it is agreed that the actual basic ageing process is due to the diffusion of carbon and nitrogen.

In the past, too many publications have attempted to apply results obtained by tensile straining a test piece to the extent of 6–10% elongation, followed by artificial ageing at 100–250° C., to those obtained after a light degree of temper rolling, although in the latter process, the yield point is suppressed in C.R.C.A. (cold-rolled close-annealed) stock by a relatively small reduction of 1% or even less, particularly when the rolling in the temper mill is assisted by tension from the reel. The present general trend is to temper roll in coils rather than in straight lengths, as Mr. Honeyman stated.

The amount of cold work is different in each case and to compare, for instance, 6% tensile straining of a specimen with an equivalent amount of cold work by temper rolling, it is necessary to cold-reduce the steel by approximately 6%, because the width of the specimen is reduced during stretching, whereas it remains constant in temper rolling.

As stated, residual stresses are absent in steels that are stretched. This fact was evidently overlooked some years ago when the Uni-Temper mill was introduced in the U.S.A., the principle of which was to stretch the coiled strip between stands to remove the yield point; this type of mill did not develop, however, as the principle of the method was wrong.

The two X-ray back-reflection photographs in Fig. 16 show that the method gives a sensitive indication of cold work, and we look forward to a publication by Dr. Hundy with his colleague Mr. P. Wright on temper rolling.* Do the photographs give any indication of residual stresses?

The beneficial effect of small work rolls in temper mills for the elimination of the yield point has been known for many years, as have the effects of roughened and sand-blasted work rolls, although these cannot be used for numerous applications (e.g. when a bright smooth surface is essential for subsequent electro-plating).

Dr. **K. W. Andrews** (United Steel Companies, Ltd.): The paper by Dr. Cina presents some extremely interesting and useful information about a property of certain steels and iron alloys which has not been by any means thoroughly explored. In this instance a notable addition to knowledge has been made. Any comments I make are not therefore intended in any adverse sense, and are mainly on small points. Firstly I am wondering whether it is justifiable to call the ferrite in fully ferritic alloys (p. 407) 'δ-ferrite.' The term 'α-ferrite' would probably be more correct. 'Delta' could reasonably be reserved for 'high-temperature' ferrite only—i.e. ferrite which may appear in steels that have been heated

* *J. Iron Steel Inst.*, 1955, vol. 181, Sept., pp. 40–43.

up and passed and through the austenite region—or ferrite which has been retained on cooling after solidification but which would have been completely replaced by austenite if equilibrium could have been reached during cooling in the appropriate temperature range.

Another point of interest lies in the author's discovery of an unstable constituent θ which he believes to represent an intermediate stage in the transition of γ to α. I was wondering why this had not been noticed before by other workers, including myself. The answer is probably given on p. 416, where the author appears to indicate that the θ phase has a much briefer spell of existence in commercial alloys; is there any reason for this? For example, does the author think that the existence of carbon atoms in solid solution in the austenite tends to inhibit the formation of θ?

Under the rather heavy deformations represented by 200% compression (as in the author's Fig. 4) one might have expected some preferred orientation to be set up. There may in fact be some evidence for this in Fig. 4. Thus, towards higher deformation at room temperature and −67° C. the amount of ferrite determined magnetically tends to be generally higher than that determined by X-rays—by amounts up to 10%. This would arise if the intensity of the diffracted X-rays was not uniformly distributed round the Debye–Scherrer ring. This observation does not seem to apply to the results for −152° C.

That preferred orientation is set up in cold-worked Cr–Ni steels of the kind studied by Dr. Cina is well known. In some work of ours the mode of deformation was more complex, since we studied hard-drawn stainless-steel wires. Preferred orientations are set up and the transformation $\gamma \rightarrow \alpha$ (or α_2) occurs. In fact, Neerfeld and Mathieu endeavoured to derive a transformation mechanism from the relationship between the crystallographic axes of the γ and α phases suggested by their respective orientations. I do not consider their conclusions were based on adequate information, although it must be admitted that their mode of deformation (simple tension) was different from ours. We started with annealed wire. The predominant orientation can be described by saying that a cube diagonal lay parallel to the axis of the wire. There was a subsidiary 'cube edge' orientation and effects arising from twinned crystals. Given the predominant cube diagonal orientation, it was then necessary to assume in turn different crystallographic relationships between γ and α according to the different modes of transformation proposed by various authors. From these relationships possible orientations of the α phase were calculated (not usually represented by simple integral indices). From the orientations the intensity distribution round the 'low-angle' diffraction rings was calculated and compared with the observed. The best agreement was obtained if it was assumed that the transformation gave rise to the orientation relationship proposed by Nishiyama and Wassermann. The results of Dr. Cina also appear to favour the same mechanism.

The orientation became sharper towards the centre of the wires and the amount of austenite transformed increased. The orientation appeared to be the same throughout but the increased scatter of the orientation at the surface might conceal minor differences. One of the difficulties here is that unless the orientation is fairly sharp more than one interpretation may be possible.

Mr. **E. L. Tinley** (Joshua Bigwood and Son, Ltd.): The material contained in the paper by Dr. Hundy on the elimination of stretcher-strains in mild-steel pressings extends our knowledge of the ageing behaviour of steel sheets which have been processed by means of temper rolling or roller levelling, and it will on this account be accepted as a valuable contribution to the available data relating to a long-standing and involved problem. I am especially interested in the design of roller levellers; this type of machine, which for many years has been regarded as one of the chief tools for the suppression of yield point, will continue to find favour so long as steel sheets having a yield-point elongation which cannot be permanently removed by temper rolling or other means continue to be used.

I agree that there is room for improvement in the design of the roller leveller, and papers such as these help greatly in developing these machines on the right lines. The co-operation of the makers of steel sheet and the people who use it for the manufacture of steel pressings are also needed. The effectiveness of the roller leveller depends on the diameter, number, and setting of the rolls. The rolls must be small enough in diameter to stress the material at the extreme fibres substantially beyond the yield point, but with light gauges the minimum diameter must be determined rather by mechanical details than by the degree of surface strain that they can produce in the sheet, although the material must be strained beyond the yield.

The deficiencies of strain per flexure are made up as far as possible by increasing the number of repetitions, i.e. the number of rolls over which flexing takes place. I have not so far found any clear statement of the relationship between the strain per roller and the total strain after a series of reversals of flexure, although Polakowski[3] has produced evidence of its cumulative effect in some of his papers on cold working and the Bauschinger effect. Further evidence is to be found by examining the roller-levelling machines described in this paper. The experimental machine used by the author has 2-in. dia. leveller rolls capable of producing surface strains of the order of 1·8% in 20-gauge sheet. That, however, is assuming that the material is flexed to a radius corresponding to that of the rollers, which in actual practice is never attained; it is always greater, to an extent depending largely on the stiffness of the sheet and the tractive effort of the rolls, which determines the amount of intermesh which can be applied. The curves shown in Fig. 5 tend to indicate that processing through this machine produces a total deformation sufficient to offset a yield-point elongation of 4–5%.

I presume that the roller leveller in question has short rolls, as the $1\frac{3}{8}$-in. dia. flexing roll is smaller than could be used in a wide machine. Although a number of press shops use levellers with a separate flexing roll, there are many which use machines without this auxiliary device and seem to get quite satisfactory results from the precision type of leveller which has, say, $1\frac{3}{4}$-in. dia. rolls for dealing with 20-gauge sheet. It is usual to provide an adjustment so that the top bank of rolls can be tilted relatively to the bottom bank and obtain a gradually decreasing intermesh from the inlet to the exit end. Improved results may be obtained if at the entering end six rolls are used with a constant intermesh.

The problem of the kinking of sheets during the levelling process has been referred to by the author. Sheets which have been heavily cold-rolled before final annealing exhibit a fine grain structure and considerable yield-point elongation, and these seem to be particularly liable to this kinking defect. It seems to be due to periodic cataclysmic yielding across the sheet, brought about by slip over the less deeply intermeshed rolls, while the sheet is being pushed forward by those which are more deeply intermeshed. This condition can be aggravated by roll wear or incorrect roll setting. The macro-stresses induced by rolling or roller levelling are uni-directional, and resistance to ageing in the transverse direction may be low, as the author has said, if the

micro-stresses are low and the reduction is not great. It has been demonstrated that an increase in these macro-stresses by heavy temper rolling increases the resistance to the return of transverse stretcher strain markings. Sheet which has been more lightly temper rolled and which shows a quick return to yield-point elongation in the transverse direction can be treated beneficially by passing the sheet through the leveller at right-angles to the direction in which it was originally levelled.

I agree that there exists an optimum combination of temper rolling and roller levelling, the temper rolling being carried out at the maker's works and the roller levelling in the pressing shop within 6–12 or 24 hr. of pressing the sheet.

Dr. **C. A. Edwards,** F.R.S. (Swansea): The reference to the spontaneous transformation of austenite into martensite in Dr. Cina's paper reminds me of an observation I made many years ago but never published, namely that in certain steels it is possible for this change to take place almost instantaneously at temperatures as low as that of liquid air. A steel containing 12·0% Cr and 1·2% C is completely austenitic and quite non-magnetic after water-quenching from 1100–1200° C. If such a specimen is then immersed in liquid air for a few minutes it becomes strongly magnetic and martensitic. The structural change can be detected by the naked eye if one of the surfaces of the specimen is polished before the liquid-air treatment.

The very careful work by Dr. Jones and Mr. Owen-Barnett represents a noteworthy advance in our knowledge of the many different features connected with strain-age-hardening. Their studies of the influence of time and temperature are particularly valuable, and they indicate the differences between the effects of nitrogen and carbon. The age hardening caused by these two elements is fundamentally the same, but there seems to be no doubt that the changes due to nitrogen take place at a much lower temperature than with carbon.

Dr. Hundy suggests that the Cottrell–Bilby theory is now generally accepted. I think that the problem of age hardening after straining can be explained quite simply. My colleagues and I have shown that when iron which contains no carbon or nitrogen is strained the metal undergoes plastic deformation like other pure metals, i.e. no yield-point step or discontinuity occurs on the stress/strain diagram. This is because there is nothing to prevent movement commencing on the planes (110) of easiest slip. When such interstitial elements as carbon and nitrogen are present they are located at the above-mentioned planes, and thereby increase the resistance to slip on such planes. In this way the stress at which movement can start is artificially raised, but once it starts, movement on the other available planes can take place at a lower stress, largely because so many are then brought into action. I should like to emphasize that this very brief statement is not intended to be a complete description of the sequence of events; all I want to stress is that the carbon and/or nitrogen atoms raise the stress at which movement can start on the 110 planes and that this is the fundamental cause of the yield-point phenomena and strain-ageing characteristics. On ageing, after straining, all that is necessary to imagine is that the nitrogen or carbon atoms move or diffuse back to approximately the same relative positions they originally occupied, and then the yield point reappears.

The effect of grain size is, of course, very important, because as the grain size decreases the yield point or the yield strain automatically increases, so that the yield strain, even in annealed low-carbon steel, may be 4% or even 5% if the cooling rates are rapid enough to prevent the crystal grains becoming large. We must always bear in mind the important influence of the degree of strain that is required to remove the possibility of stretcher strains developing.

Dr. Hundy found that the effects of testing after strain ageing are not the same when testing transversely as when testing in the direction of rolling. That must be due to what I would describe, for want of a better term, as incipient preferred orientation. As the cold work increases there is a possibility of increasing the preferred orientation by subsequent annealing, and therefore, as Pfeil and I found many years ago, by straining at 2% followed by suitable low annealing it is possible to transform millions of tiny crystals into a single crystal; preferred orientation produced by the low degree of strain would account for the variations.

On p. 128 Dr. Hundy says "This process is repeated from grain to grain . . ." etc. He is explaining the propagation of Lüders lines; if he looks up some of my papers, he will find that that is exactly what I say.

Mr. **D. C. Finch** (Pressed Steel Co., Ltd.): I should like to support Dr. Hundy's suggestion that a cheap machine for the removal of stretcher strains from mild-steel sheet is a possible development as a result of his recent work. I think, however, that too little attention has been paid to the importance of grain size in all the work carried out in connection with the stretcher straining and strain ageing of mild steel.

My own experience is that stretcher strains occurring after ageing in medium- and large-grained material have been quite easily removed by roller-levelling, whereas it has been impossible to remove them from fine-grained material, even with the most exacting roller-levelling treatment. It has also been found that one of the more recent designs of roller-leveller, incorporating small-diameter rolls and a flexing roll, has been almost entirely capable of removing the stretcher strains from as-annealed material. It is quite probable that this machine would be completely successful if it were used on large-grained material. Grain size, which has been neglected so far, should, therefore, be considered in any further work which is done on this subject.

AUTHORS' REPLIES

Dr. **B. Cina**: I wish first of all to thank Dr. Hoar and Dr. Andrews for their kind opening remarks. Dr. Hoar referred to the rate of isothermal transformation of the austenite. I believe that this is rather a complex phenomenon and that it is a function of the actual temperature of ageing, the magnitude and nature of the attendant quenching stresses, and also of the composition of the alloy. To amplify that, so far as temperature of isothermal transformation is concerned, obviously the lower the temperature is below the M_s point the greater is the amount of the martensite which would be expected to form, and therefore the faster the rate at which one would expect it to form. On the other hand, the higher the temperature (although still below the M_s point) the greater will be the magnitude and number of thermal fluctuations and therefore the faster will be the rate of transformation. What obtains, therefore, is a sort of compromise between the two influences. The actual rates of transformation which I observed in the 16/8 Cr–Ni alloy at 97° C. and at room temperature indicate that the extent of transformation is influenced more by the degree of undercooling below M_s than by the thermal fluctuation factor. The similar rate of transformation for the 16/8 Cr–Ni alloy at 97° C. and the 18/8 Cr–Ni alloy at 17° C. may be explained by both alloys being undercooled below their respective M_s to a similar extent.

Quenching stresses also can have a marked effect both on the rate and on the extent of the isothermal martensite formation, and thus I show in the paper that for the

same small sample, 44% α was obtained on rapid quenching from 850° C. to room temperature, but only 8% α was obtained on furnace cooling.

Dr. Hoar has also drawn attention to the difference in time scale for isothermal martensite formation in his commercial 18/8/3/1 alloy and that obtaining for the pure 16/8 and 18/8 Cr–Ni alloys in the paper. It is of interest that a time scale of about 30 hr., and therefore similar to that of Dr. Hoar's, has been observed[4] for isothermal martensite formation in a commercial 18/8 Cr–Ni alloy. It is tentatively suggested that the more sluggish transformation in both commercial alloys may in part be due to the additional alloying elements present in them, e.g. C, N, Mn, etc.

Dr. Hoar said that we might have to view martensite formation as being inhibited by stress rather than induced by strain. So far as elastic stresses are concerned, compressive stress can certainly have an inhibiting effect, as Cohen and his co-workers[5] in the U.S.A. have shown, although elastic tensile stresses can actually favour the martensite transformation.

Dr. Hoar also said that we may have to alter our ideas on the actual mechanism of the martensite transformation. It is dangerous to generalize here, because I do not think that we shall be able to apply one type of mechanism to all martensitic transformations, and certainly not to all $\gamma \rightarrow \alpha$ martensitic transformations so far as different alloy systems are concerned. Thus, to illustrate only two complicating factors: free energy considerations in certain Fe–Mn and Fe–Ni–Cr alloys are such that the $\gamma \rightarrow \alpha$ transformation occurs through an intermediate phase of hexagonal close-packed structure, whereas the martensitic transformation from γ to α in other ferrous alloys occurs directly from face-centred cubic to body-centred cubic lattices. Secondly, most of the work done on martensite formation has been done on alloys containing appreciable amounts of carbon, in which case, of course, the lattice formed on quenching is not truly body-centred cubic, but body-centred tetragonal, owing to the carbon content, so that we should not expect the same mechanism of transformation to apply as in a carbon-free alloy.

Dr. Andrews drew attention to the importance of distinguishing between the δ phase and the α phase. I agree with him, and in a footnote on p. 506 I specifically define the δ phase as " the b.c.c. phase stable at elevated temperatures " and the α phase as " that formed by transformation of the austenite at lower temperatures by cooling or by cold-working."

Strictly speaking, Dr. Andrews is correct in that the b.c.c. phase first formed from the liquid in Fe base alloys should be called α and not δ, in line with the nomenclature in non-ferrous alloys. However, since the term α ferrite now implies formation from γ stable at a higher temperature, I feel that for Fe–Cr alloys containing more than 13% Cr the term δ ferrite should be used for consistency, since such alloys never pass through a f.c.c. stage.

He refers to the fact that the θ phase has previously not been detected by any workers in studying the Fe–Ni–Cr system, and says that this may possibly be attributed to the presence of carbon in most of the alloys with which these workers have been concerned. I quite agree. In American work[6] on Fe–Mn alloys, it was found that as the carbon content was increased, so it tended to inhibit the actual formation of the h.c.p. ε phase, and if the carbon was high enough the austenite transformed directly to α without any intermediate hexagonal phase at all. The same situation probably obtains in Fe–Ni–Cr, and that is why there is only a suggestion of θ in the commercial 18/8 alloy, as compared with a substantial amount in the purer material.

He refers to the effect of preferred orientation due to cold work and suggests that at any rate with high degrees of cold work a high state of preferred orientation may have been developed, and this may explain why I measured less α by X-ray than by magnetic methods. The magnetic method is certainly the more accurate one in detecting the α phase since it is very much less influenced by the orientation of the α than the X-ray method. The X-ray grazing incidence technique used did indicate the presence of preferred orientation in heavily cold-worked samples although not to such an extent as to obviate the use of the method.

It is most interesting to have Dr. Andrews's confirmation of the orientation relationship between the γ and α_2 phases, and I look forward to reading a fuller account of his work. I wonder whether the increased scatter in orientation found by Dr. Andrews towards the outside of his wire may be due to tensile stresses developed in the centre of the wire and compressive stresses on the outside during drawing. This would also explain the results obtained by Hobson, Chatt, and Osmond,[7] who found more α in the centre of some cold-drawn stainless wire than at the outside.

Dr. Edwards referred to the retention of austenite in a 12% Cr, 1·2% C alloy. This is interesting, because it illustrates the stabilizing effect which chromium can sometimes have on austenite. Thus, whilst an addition of only 1·2% C to iron would result in only about 14% γ being retained on quenching from the fully austenitic region,[8] the simultaneous addition of 12% Cr in Dr. Edward's alloy has caused all the γ to be retained on water-quenching. The addition of 12% Cr to iron without any carbon would have given a fully martensitic (α) structure on quenching, i.e. Cr in the presence of C has the same stabilizing effect on γFe as in the presence of Ni.

Dr. **B. Jones**: Mr. Honeyman refers to the effect of a small grain size in increasing the rate of strain ageing, and mentioned some disparity between our results and those of Dr. Hundy, in particular that we say that ageing continues for a very prolonged period, namely 3 years (and I mentioned 5 years in the discussion), whereas Dr. Hundy said that it was complete in 12 weeks. I can only confirm that, as stated in our paper, the rate of ageing slows down appreciably after 1 year, and we have found that it continues to some extent for some years; I cannot agree that it is complete in such a short time as 12 weeks.

With regard to the reference quoted by Mr. Honeyman on p. 219 of our paper, we regret that owing to a misprint, this should have been reference 18 and not 19 as printed. In this reference Richards, whilst commenting upon the tempering of carbon steels in the temperature range 200–350° C., stated " It also seems reasonable to conclude that macro-residual stresses will be re-distributed during tempering and that the way in which they are re-distributed will depend upon the tempering temperature." Another pertinent reference appears in " Metals Handbook " (1948 Edition) on p. 238: " Moderate heating sometimes produces a greater amount of stress relief than can be explained on the basis of increased relaxation or decreased yield strength. For example, residual stresses in steel are somewhat decreased as a result of heating to about 400° F." The relief of residual stresses allows the carbon and nitrogen atoms to migrate at a faster rate at temperatures of 200–250° C.

Dr. Edwards's comments are most welcome, and I am very pleased to see him here today. He mentioned the difference in the effects of nitrogen and carbon. We agree with him, and we put the blame very much more on nitrogen than on carbon, because (*a*) the solubility of nitrogen ($< 0{\cdot}001\%$) is many hundreds of times more than that of carbon (0·0000001%), and (*b*) the diffusion of nitrogen in α iron is much faster than that of carbon.

In all our work on temper rolling and tensile stressing we find that nitrogen reacts very much more than carbon. In confirmation of this, we have tested the strain-ageing of pure iron, a sample of which was supplied by B.I.S.R.A. It contained very low carbon (0·006%) and 0·001% of nitrogen. We found that the rate of ageing with this pure iron, which I always thought of in my youth as non-ageing, was almost the same as that of open-hearth steel. The results will be published shortly in the *Journal*.*

I was very interested in Dr. Edwards's statement that he did not fully accept the Cottrell–Bilby theory. For many years I did not do so. We say in the paper that it is more generally accepted that the older theories, but the views expressed by Dr. Edwards have received a great measure of support from metallurgists.

Dr. **B. B. Hundy**: I must agree with Mr. Honeyman that there are a number of difficulties to be overcome before a processing machine can be introduced into the press shop that will accept annealed sheet or strip. The idea is so attractive, however, that I feel we must make every effort to try and overcome these difficulties. I also agree that it is difficult to find the optimum combination of temper rolling and roller levelling on a strip mill; as well as the points that Mr. Honeyman mentions, scatter in the results can also arise if the samples are not taken from the same part of the ingot or if they are bent at all during the cutting from the strip.

With regard to the question of accelerated strain ageing, I agree with Dr. Jones that his results are in quite good agreement with my own, at least for ageing times up to 3–6 months. After this length of time, ageing is proceeding rather slowly and it is perhaps not surprising that it is not always possible to get good agreement with the theoretical relation for long ageing times. The relation, however, certainly seems to be valid for the first few months of ageing and this period is the most important in practice.

Mr. Honeyman's point about the interrelation of creep, strain ageing, and brittle fracture should be looked into. There is probably some fundamental phenomenon which affects all three properties, although at present it is not possible to say exactly how they are related.

Like Mr. Honeyman, I too wish we could create a fashion for having car roofs with stretcher-strain patterns—life would be very much easier. I have to admit, however, that I prefer my own car without them.

Dr. Jones asks about the accuracy of my residual-stress measurements. The January issue of the *Journal* contains a detailed account of this work and the question of the accuracy is discussed there. In these tests I think the stress would be correct within $\pm \frac{1}{2}$ ton/sq. in. Boiling in water for 2 hr. did not seem to affect the residual stresses at all. The residual-stress patterns could possibly be confirmed by X-ray methods; they would, however, be rather tedious and we did not do any tests of this sort. The steel used in this work was subcritically annealed and I associate the rather low yield-point elongation solely with the method of testing. In this work we used a Hounsfield tensometer and tested very slowly: now, however, we record the stress/strain curve autographically and test at a higher strain rate, when a similar steel has a yield-point elongation of about 6%.

There has been some discussion on the relative rates of ageing of stretched and rolled mild steel. My own experience suggests that the *rate* of ageing in the early stages is fairly independent of the method of working and of the actual amount of work done. The *amount* of ageing (i.e. the change in properties on complete ageing), however, is very dependent on the amount of work done. I think that the main difference in behaviour between stretched and temper-rolled steel is due to the fact that stretching involves a plastic strain of $> 6\%$, whilst temper rolling only involves about 1·5% strain. I think that sheet temper-rolled 5% would behave in a very similar manner to sheet stretched 6% (ignoring the yield point which is affected by residual stresses).

Mr. Wright and I think that the back-reflection X-ray diffraction photographs mainly show the breakup of the grains due to cold work; we do not think that they give much indication of the residual stresses present.

I agree with Mr. Tinley that the roller leveller will remain a most useful machine for a long time to come and I am sorry that I am unable to answer his questions on the relation between the amount of strain for each flexure and the total effective strain due to a number of flexures. Some work on the mechanics of roller-levelling, however, is being sponsored by B.I.S.R.A. at Sheffield University and I hope that eventually we will be able to answer such questions with a fair degree of confidence.

Dr. Edwards's work on strain ageing is very well known and I agree with him that most of the trouble is due to nitrogen. His work on the stabilizing action of such elements as vanadium shows that carbon is not very important in room-temperature strain ageing and it is only at 200–250° C. that it seems to become troublesome. I am myself a convert to the dislocation theory of strain ageing because so far I have not come across any strain-ageing phenomena which it cannot explain and, what is more, the theory often gives *quantitative* agreement with practice. It is my impression that the dislocation theory can be regarded as a general extension of Dr. Edwards's more specific theory, in that it considers exactly how the solute atoms increase the resistance to slip on the slip planes.

Dr. Edwards, Mr. Finch, and Mr. Honeyman all raise the question of the effect of the grain size on the strain-ageing behaviour. I think that everyone agrees that this is most important and it seems unfortunate that, under modern conditions, it is very difficult to produce steel sheet with a larger grain size together with good ductility.

I cannot find myself in agreement with Dr. Edwards on the question of the strain-ageing anisotropy of steel sheet. Additional tests to those reported here showed that the initial preferred orientation of the sheet was not affected by rolling reductions less than 5%, and it seems to me that this yield-point anisotropy can be explained simply by consideration of the relative increases in the macroscopic and microscopic residual stresses as the reduction is increased.

I would like to assure Dr. Edwards that I did not intend my description of the propagation of a Lüder's line to be regarded as an original idea; I only put this into my paper to give a clear idea of what happened when mild steel yielded plastically.

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FATIGUE TESTS ON ROLLED ALLOY STEELS

This discussion was based on the paper by Mr. P. H. Frith entitled **" Fatigue Tests on Rolled Alloy Steels made in Electric and Open-Hearth Furnaces,"** which was published in October, 1954, as Special Report No. 50 in The Institute series. A summary was printed in the May, 1955, *Journal*.

Mr. **P. H. Frith** (Bristol Aeroplane Co., Ltd.) presented the paper.

Dr. **H. H. Burton** (English Steel Corporation Ltd.): As Chairman of the Inclusions Sub-Committee I am very pleased to be asked to open this discussion because of my long association both with the author and with the work on fatigue.

His title is extremely modest, because he has referred only to fatigue tests on electric and open-hearth steels, but in fact he has covered much more ground than that and has gone a long way towards explaining, so far as present knowledge goes, the reasons why these types of steel differ in their fatigue properties. I have seen this work at all its stages and so will not go into too much detail, but I should like to refer to some important considerations in drawing conclusions from the author's work. First of all, I hope that it will not lead to a sort of panic effort on the part of steel users to switch over from a process which already gives them perfectly satisfactory results to something else which they may think contains less spherical inclusions of the non-deformable type. I know that the author is very conscious of this possibility and has done his best to safeguard against it.

Secondly, the paper raises grave doubts about the present trend, which I believe is particularly pronounced in the U.S.A., to go in for what are called ultra-high tensile strength steels. Neglecting for the moment the ball-race steels, the other steels which are used widely in aircraft and other highly stressed mechanisms are such that there is little to be gained in fatigue by going up to these very high tensile strengths. What is the use of increasing the proof stress up to some sky-high figure if there is not a corresponding improvement in the fatigue properties ?

Mr. Frith has analysed ball-race steels very well indeed and they bear out strikingly the conclusions which he has drawn; I repeat my suggestion that it is a pity that more British acid O.H. steels were not tested. I feel that his figures were unduly weighted by one cast, which gave rather poor results. The other cast gave results at least as good as the neutral O.H., and it is easier to get them in that way than by neutral O.H. methods. It is also unfortunate that we have so few results for acid electric steels, but then there are so few acid electric furnaces operating in this country.

Some of the specimens which the author tested were provided by my own firm. Almost immediately after we had supplied this steel we had for other reasons to change our lining to basic, so that no more specimens were forthcoming.

I hope that another result of this eagerly awaited paper will be completely to debunk the ideas about the terrible effect of any type of non-metallic inclusion whatever. In specifications it has been common to say that the steel 'shall be free from harmful inclusions.' No one has defined what a 'harmful inclusion' is, but from that has grown a general view that all inclusions of whatever size or shape must be harmful, and so a great deal of very good steel has been unnecessarily rejected.

I should like to express my personal indebtedness to the author and his colleagues for the magnificent effort, which they have made. It will, I know, be agreed that this is indeed a monumental paper.

Mr. **R. Wilcock** (Samuel Fox and Co.): This has been a very thought-provoking paper, and in particular the work on steels tested at 750 D.P.N., i.e. the ball-bearing steels. I propose to confine my remarks to this part of the work.

I wish that Mr. Frith had said more about the significance of these tests in relation to the suitability of steel for a bearing, and particularly the endurance value obtained at a figure much above the fatigue limit, because there especially the results must have been influenced by scatter. We have found that scatter is considerable in ball-bearing steels, and extreme cases taken from a large number of tests (at $\pm$ 55 tons/sq. in.) are:

B.E.A.	13,892,000 *B*	A.O.H.	4,791,000 *B*
	27,000 *B*		28,000 *B*

We tested a number of steels in duplicate, making tests from the same bar. These are admittedly extreme examples, but they do show that the results of single tests may be misleading.

We have also done tests on various parts of the cast, and here again we found a good deal of scatter, but no consistency; sometimes the first ingot in a cast gave the best results, whereas in later casts it might be the last. In addition, in nine casts we have forged a test piece in some cases and rolled it in others, all from the same billet; again there is a good deal of scatter—sometimes the forged being better and sometimes the rolled—so that it is difficult to draw any valid conclusions with the steels tested well above the fatigue limit.

There is a suggestion on p. 102 that it may be an advantage to carry out tests on steels at this particular stress level to see whether they are satisfactory. It may be valid, perhaps, to take the fatigue limit, but is it valid to take an endurance level at this stress value when there can be so much scatter ? We feel that the scatter is fundamental and is not due to our testing methods. The testing was done on a rotating-beam machine with 4-point loading. We are dubious about the value of such a specification, although there may be some justification in using the fatigue limit as a basis for approving a method of manufacture rather than individual casts. We have tested more than 50 casts at this stress level, and the results are summarized in Table *A* (cf. Frith's Table XLVIII).

Electric-arc steel does not appear in quite such a bad light as in the paper, and the top line shows the first

Table A

RESISTANCE TO BREAKING AFTER 5×10^6 REVERSALS AT $\pm$ 55 tons/sq. in.

Test Batch	Basic Electric-Arc Quality		Acid Open-Hearth Quality	
	No. of Casts in Batch	Casts Withstanding Reversals, %	No. of Casts in Batch	Casts Withstanding Reversals, %
I	14	50	2	50
II	13	15	7	71
Total	27	33	9	67
Frith's data	20	5	8	50

Table B

EFFECT ON ENDURANCE OF MODIFYING STEELMAKING PROCEDURE

Cast No.	Steelmaking Procedure	No. of Reversals at Stresses of:			Average Hardness, HD/30
		± 45 tons/sq. in.	± 50 tons/sq. in.	± 55 tons/sq. in.	
		Steels arranged in order of merit			
Fox steel S4753	Normal, but longer refining time to obtain lower S content	...	139,782,000 *UB*	24,415,000 *UB*	716
S4752	Normal	21,248,000 *UB*	21,401,000 *UB*	11,257,000 *B*	737
S5158	Cement clinker slag	...	20,568,000 *UB*	11,621,000 *B* (2,378,000 *B*)	711
S5148	Deoxidized with CaSi at ' slag off '	25,635,000 *UB*	20,871,000 *UB*	8,050,000 *B* (281,000 *B*)	727
S5149	Deoxidized with zirconium silicide	20,944,000 *UB*	20,903,000 *UB*	3,795,000 *B* (4,666,000 *B*)	740
H3738	FeB added before tapping	29,740,000 *UB*	20,970,000 *UB*	2,597,000 *B* (306,000 *B*)	712
H3381	Deoxidized with Al in bath	20,526,000 *B*	10,679,000 *B*	3,452,000 *B*	722
H3782	Normal CaSi in ladle	1,551,000 *B*	704,000 *B*	433,000 *B*	725

B = Broken; *UB* = Unbroken

series of tests in which there was nothing to choose between the results for the electric-arc and the acid O.H. steels. The second line gives further results where the electric arc was poor.

We have also made a number of modifications in the electric-arc practice and the results are given in Table *B*.

It is a pity that Mr. Frith was not able to obtain the information about the various steelmaking processes. I have tried to give the relevant points relating to a few modifications and they are tabulated roughly in order of merit, so far as we can judge them within the limitations imposed by scatter. The first cast was normal, although it had rather a long refining period, and gave quite good results. We used a cement clinker slag which was largely aluminous, and tried various deoxidation methods using calcium silicide in place of the more usual ferrosilicon immediately on putting on a new slag, and also zirconium silicide, and even boron. We were a little disappointed, in view of the suggestions in this paper, that the aluminium-treated steel did not show any marked advantages. We are not convinced, however, that the results shown are really significant and that that order of merit really matters, but the top result seems to suggest that the fatigue limit is nowhere near so low as 38 tons/sq. in.

Dr. **H. Sutton** (Ministry of Supply): The question of directionality of properties in the very highest strength steels is of special interest to engineers. I have been trying to compare some of the very interesting data in this paper with the data published by two American investigators, Ransom and Mehl, whose paper perhaps was not available when Mr. Frith made his review.

They studied fatigue anisotropy in the American steel *SAE* 4340 and used some heats which showed high average tensile reduction of area in transverse tests, and others showing low values. They attempted to correlate fatigue properties in the longitudinal and transverse directions with the average reduction of area shown in transverse tensile tests, and on their own casts of material it did appear that there was some correlation. They concluded that the average transverse endurance limit was about 84% of the average longitudinal endurance limit in the steels having a higher reduction of area in the transverse tensile test, and only about 68% in steels showing low reduction of area in the transverse tensile test. They said that they thought that these effects were due to fragmented string-type inclusions. It appears that Mr. Frith's results do not really show a similar trend of behaviour as between transverse ductility and ratio of transverse to longitudinal fatigue properties. I should be glad to know whether the author has looked into this question.

The behaviour of steels at short endurances and very high stresses has been touched on by Mr. Wilcock, and I agree with him that that is important. There are many applications in which during the whole life of a particular component we do not have to go to very high endurances, and it is a good thing to pay attention to performance at the higher stresses. There are, on the other hand, very many and perhaps more exacting conditions of use in which the stress cycles number a great many millions, and perhaps those are really the more important; but there is a natural tendency to emphasize unduly the behaviour at very high endurances, and sometimes to forget the behaviour at the shorter endurances.

Mr. **W. E. Bardgett** (The United Steel Companies Ltd.): The author has shown that inclusions are not generally detrimental in the longitudinal or transverse directions in specimens heat-treated to 60 tons/sq. in. but in 80-ton and particularly 100-ton tensile steel, inclusions may definitely be detrimental. In the higher tensile steels the deleterious effect of inclusions becomes manifest by the appearance of a white area near the surface having an inclusion at its centre, this being the origin of fracture. It is not altogether clear why fracture should commence at an inclusion below the surface in preference to one at a position on the more highly stressed surface, although the author's view is probably the correct one. These results prompt the question: what effect would inclusions have if the conditions were such that failure commences below the surface in a 60-ton steel? We have carried out tests which throw some light on this aspect of the problem.

On nitriding a steel, fatigue failure always starts below the surface at the junction of the case, which is in compression, and the core, unless stress concentrations are high or the stress gradient from surface to centre very steep. As in the case of the high-tensile steels, a white area indicates the origin of fracture with an inclusion at the centre. Thus by nitriding, an interesting assessment of the effect of inclusions can be made.

Table C

TESTS ON NITRIDED 3% Cr–Mo STEEL

Section	Limiting Fatigue Stress		
	Maximum Applied Stress, ± tons/sq. in.	Stress at Fracture, ± tons/sq. in.	Difference, tons/sq. in.
Longitudinal			
8 in. sq.	44·25	41·5	−2·75
4 in. sq.	45·5	44·7	−0·8
1 in. sq.	46·5	46·2	−0·3
Transverse			
8 in. sq.	27·0	19·3	−7·7
4 in. sq.	26·5	25·5	−1·0

The tests to which I will refer were carried out on a 3% Cr–Mo steel heat-treated to 67 tons/sq. in. Specimens were cut in the longitudinal and transverse directions from 8 in. sq. and 4 in. sq. billet and in the longitudinal direction from 1 in. dia. bar and tested in a Wöhler rotating cantilever machine with results shown in Table *C*.

The maximum applied stress, as the term implies, is based on the maximum load applied to the specimen, whilst stress at fracture is the actual stress calculated on the basis of the position of the fracture, which in certain cases took place at a position corresponding to a stress appreciably lower than the maximum.

In the case of the longitudinal specimens, the difference between the limiting fatigue stress on these two bases is greatest for the largest section and decreases with cross-sectional area, indicating that inclusions can have quite a marked effect on the fatigue strength in the 8 in. sq. section and that their effect diminishes with section size.

Transverse specimens show a still greater difference than the longitudinal specimens, but it is interesting to note that the practical effect of inclusions is relatively small in sizes of 4 in. sq. and less.

Mr. Frith has made a critical examination of the fatigue properties of ball-race steels using the rotating cantilever type of test. In considering failure of this type of steel, it is important to know whether his type of test does actually assess the relative service behaviour of steels.

With the object of clearing up this point and also to provide a simple simulative test for accurately assessing steels, we have, with the co-operation of a number of people including the Skefco Co., the Hoffmann Manufacturing Co., and Samuel Fox and Co., developed a machine which was designed by the Hoffmann Manufacturing Co. and which shows considerable promise. It is obviously necessary to have a specimen which can readily be machined and this has been achieved by using a standard 3 in. dia. race, one grooved bearing being removed and replaced by a plain specimen, the three parts of the assembly being shown in Fig. *A*. Half the balls have been removed from the race, the object of this being to double the load without having to apply extra weights. Figure *B* shows the first machine constructed. This consists of a motor driving a spindle mounted vertically with a thrust bearing at the top and located in two radial-type ball races. The specimen is inserted at the bottom and is loaded through a plate and a single ball located at the end of a lever, the speed of rotation of the machine being about 1000 r.p.m.

A second, similar type of machine (Fig. *C*) has been constructed in which the spindle has been reversed so that the specimen is located on the top, facilitating assembly and removal. The type of failure produced in this machine is identical with that experienced in service, namely, a small pit showing fatigue characteristics. From the limited test results which we have obtained, the indications are that a very regular type of stress/endurance curve will be obtained with a relatively small amount of scatter. This method still requires further exploration but the indications are that it will give a ready and reliable assessment of ball-race steels.

Professor **G. W. Austin** (Cambridge University): Two features strike me on reading the author's report. He has shown, as Dr. Burton has told us, that with increasing strength and hardness the fatigue strength hardly comes up to our expectations. I think that that is a very general point. As the resistance to deformation of a material increases, we do not quite get the strength expected. This seems to override his detailed work.

The author has also carried out detailed studies of steels made by different processes, and as the strength increases there is such a falling off in the strength, we would expect that there must be some other factor at work. We have a theory or mental picture that fatigue is a process of deformation; if we have a reduction of area in a given type of steel in the tensile test, and the load/extension curve is arrested earlier, it does not deform as readily; and just as with an increase in strength diminishing our expectation of fatigue, I should expect steels of the same tensile level but poorer in the reduction of area, to show also poorer fatigue properties.

My third point is a small one. After we have congratulated the author on the work he has done, I think we can venture to indicate that if he gives us occasionally the results with a different type of machine, say a push-pull machine, it might throw even more light on his researches and conclusions. In the rotating bend machine the surface plays a very important part, as it does, indeed, in the application of many of these materials, but from the fundamental standpoint the use of a push-pull machine may help him in any further work which he contemplates.

Dr. **M. L. Becker** (B.I.S.R.A.): Without wishing to repeat what has already been said it would be appropriate for me, on behalf of the Research Association, to express thanks to the author of the report and to the Bristol Aeroplane Co. for the large amount of fatigue testing and associated work which has been carried out so assiduously in co-operation with the steel industry during the course of this long investigation. At the start, neither the industry itself nor the Research Association possessed the necessary testing facilities. The Fatigue and Inclusions Committee has been fully aware of these limitations and strongly recommended that at the new Sheffield Laboratories B.I.S.R.A. should put down a number of fatigue-testing machines to carry on this type of work. This has been going on now for a year or two so that before long we should be able to place before the Institute the results of further work following up, or on parallel lines to, that reported here.

Dr. **N. P. Allen** (National Physical Laboratory): What impresses me most strongly is that if at the beginning of the work we had said 'What is the maximum fatigue strength that we can reasonably expect to get in a steel?' the author would probably have replied with some comparatively modest figure of 30–40 tons/sq. in.; but, for reasons which are not at all clear, it has nevertheless been possible to push up the fatigue strength of these strong steels quite considerably, and fatigue limits of 50 tons/sq. in. are now available. This has been done by modification of steelmaking procedure and is a notable advance.

The question arises whether we have now reached the limit or whether it is possible that in due course we shall

have available steels with a fatigue limit of 70 tons/sq. in. We ought not to be too easily persuaded that we have reached the limit of progress. The difference between steels made in different ways is a very striking, useful, and encouraging one, but we have no theoretical guidance to show us whether to expect the fatigue strength to rise hand in hand with the general hardness or not. We do not know why it is that as the strength increases the fatigue limit tends to lag behind.

Fatigue is strongly associated with plastic deformation, since it is only when repeated plastic deformation occurs that a fatigue crack appears. We should therefore expect that, if we put up the yield-point of the material by putting obstacles in the way of plastic deformation, we should increase the fatigue strength proportionately. It may be that we never put up the yield-point of the material uniformly, but always in such a way that, although the average yield-point of the material is increased, some spots are always weak. Greater fatigue strength might then be expected by improving the uniformity so as to eliminate the weak spots. On the other hand, it may be that since we often obtain a high yield-point by bringing the material to a somewhat unstable metallographic condition, the unfortunate effect on the fatigue limit is somehow connected with the instability that is thereby introduced.

Mr. **E. Ineson** (B.I.S.R.A.): One point on which I would welcome further information concerns the method of assessing the fatigue limit. I understand from the paper that the horizontal portion of the stress/endurance curve is considered to be established when a test piece remains unbroken after a given number of cycles. What measure of confidence does the author place in this assessment?

Experiments in our laboratory with an alloy steel heat-treated to 60 tons/sq. in. U.T.S. have shown that the stress range between 5% confidence and 95% confidence in the fatigue limit, i.e. between 5% unbroken and 95% unbroken test-pieces after 30×10^6 cycles, is greater than 2 tons/sq. in. Ten test-pieces were tested at each of ten predetermined stress levels straddling the fatigue limit. We have no data as yet for higher strength materials.

The author refers to pronounced scatter of fatigue-test results and offers several metallurgical reasons for this. Our enquiries lead us to believe that scatter of fatigue results is inevitable and arises first of all from material variations and secondly from testing procedure. The first of these cannot be adequately investigated without a full knowledge of the second. We have carried out experiments in our laboratory to assess the reproducibility of single machines and the variability between 12 similar machines working under similar conditions. With very careful attention to specimen preparation and to the method of testing it was found that reproducible results could be obtained with particular machines. Significant differences were found, however, between results obtained from each of the twelve machines. A further comparison with six other laboratories employing basically similar methods showed significant and rather inconsistent variability between laboratories.

I wonder, therefore, whether it will be possible to gain wide acceptance of the author's proposal of a fatigue specification for steels until more is known about the factors contributing to variability of fatigue tests.

The author has successfully employed microradiographic techniques for identifying inclusions and for studying their shape and size in the steel. I should, however, be interested to know how many samples were examined from each test-piece and what steps were taken to ensure that samples were sufficiently representative of the material. It seems to me that this aspect must be equally as important as it is for inclusion counting.

Dr. **H. H. Burton**: Many speakers have concentrated almost entirely on the ball-race steels, which are a part of the investigation given almost gratis by the author in this paper. The main work which was done, in line with the work of the Inclusions Sub-Committee, was on steels of 60–110 tons tensile strength. The definite establishment of this reduced maximum stress ratio had never been clearly brought out before or the difference between the different types of steel. There had been hopes or fears that some such phenomenon might exist, but the author has put it on a definite basis.

Commenting on one statement made by Professor Wesley Austin, all these questions of the possible effect of transverse reduction of area have been considered not once but hundreds of times by the Sub-Committee, and the fact is that the steels which gave the highest transverse reduction of area gave the poorest longitudinal fatigue properties. If 100-ton tensile steels were tested of the type which will give that tensile strength after being tempered at a temperature of the order of 600° C., a probable factor in this lower fatigue limit in the high-tensile steels might be eliminated, namely internal stress, which is very difficult to evaluate.

In conclusion, I suggest that during the discussion in writing, more attention should be paid to the 60–100 ton tensile steels and less to the ball-race steel.

Dr. **B. Cina** (Brown-Firth Research Laboratories): The author has realized the importance of measuring the amount of any retained austenite which there may be in his materials. If there are any particles of austenite in the fatigue test-piece, they will have yield and ultimate tensile strength values quite different from those of the remainder of the material, and particularly so in the high-strength alloys; this may have a marked effect on fatigue strength. I am concerned, however, about the method of determining the amount of this austenite. If it was determined on a fatigue sample prepared in the normal way, there would be a definite tendency for any austenite present at the surface to be transformed to ferrite by the cold work introduced by machining and final emery papering. Because of this, one might detect very much less austenite than was actually present immediately below the surface, where in fact the failures seem to have initiated. The author states that all samples were finally polished with 00 emery paper. Some recent work at the Brown-Firth Research Laboratories has shown that this fine emery paper alone can introduce cold-work effects. Thus, a sample of En 31 of the following analysis:

Cast No.	C, %	Si, %	Mn, %	S, %	P, %	Cr, %	Ni, %
77228	1·01	0·26	0·35	0·010	0·016	1·36	0·16

was treated for ½ hr. at 850° C., oil quenched, sectioned, mechanically polished as far as 000 emery paper, and finally electropolished for 5 min. to remove cold-work effects introduced by mechanical polishing. Subsequent X-ray examination of this surface revealed 9% retained austenite. This electropolished surface was then abraded with 00 emery paper and re-examined by X-rays. Only 4% austenite was now detected showing that 5% had been transformed by the cold work from the 00 emery paper.

Furthermore, since the materials on which the work was done were all supplied hot-rolled or fabricated to different dimensions, I would expect them to have different grain sizes after final heat-treatment. Since we believe that grain size has some effect on fatigue strength, I wonder whether the author has considered the grain-size factor in interpreting his results.

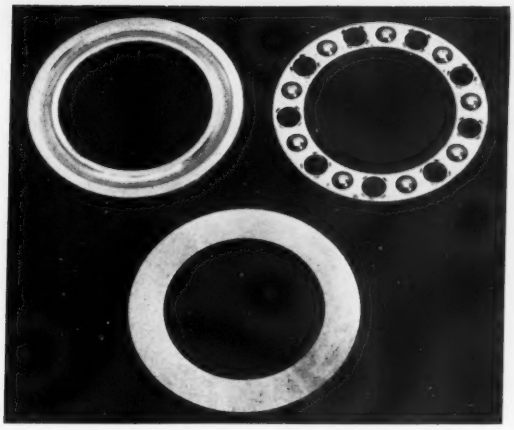

Fig. A—Standard race with plain specimens

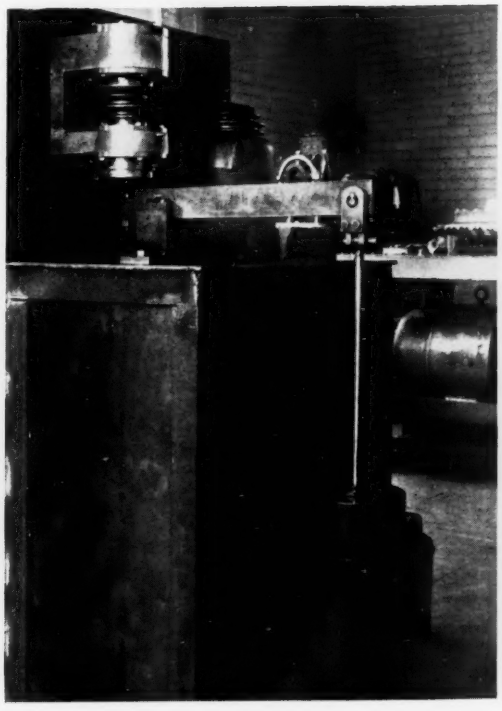

Fig. B—Machine for assessing steel behaviour: specimen mounted at bottom

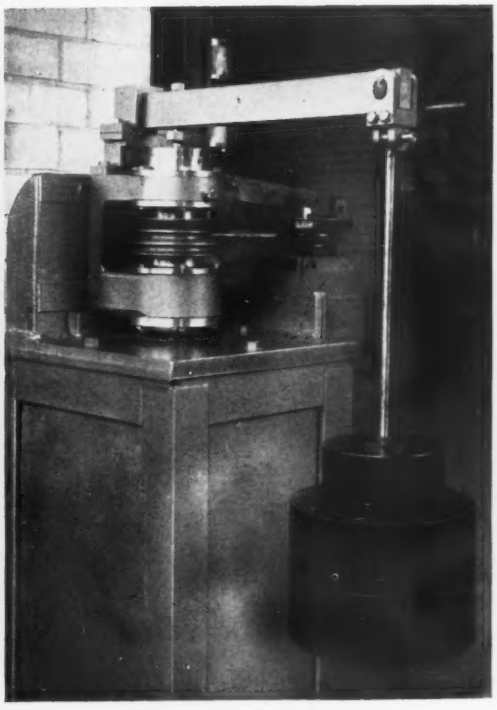

Fig. C—Second type of machine with specimen mounted at top

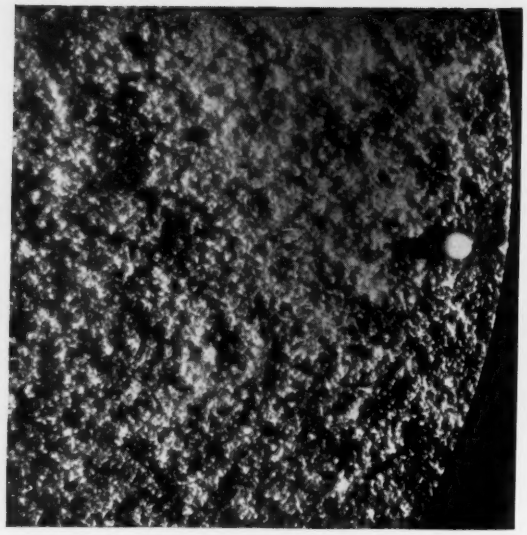

Fig. D—Photomicrograph showing an inclusion in a fractured fatigue specimen. Oblique illumination × 30

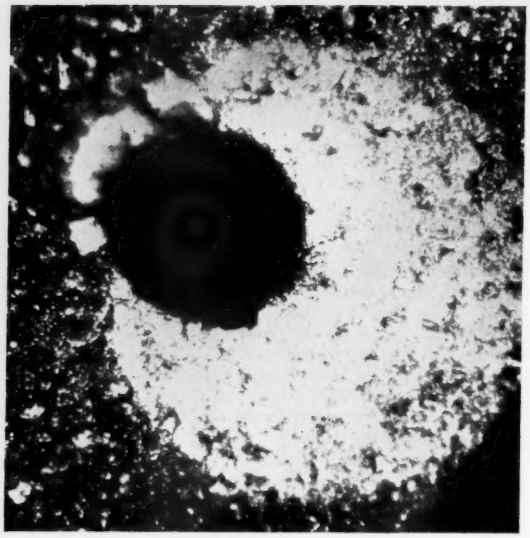

Fig. E—Photomicrograph of inclusion in Fig. D. Bright-field illumination × 250

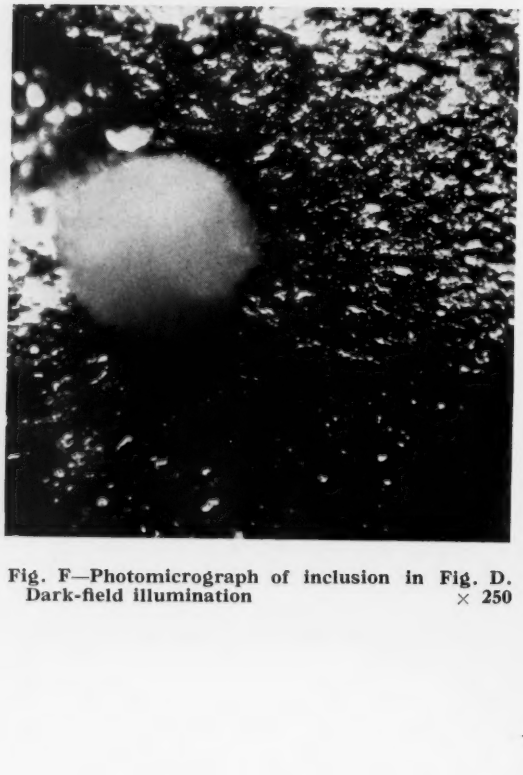

Fig. F—Photomicrograph of inclusion in Fig. D. Dark-field illumination × 250

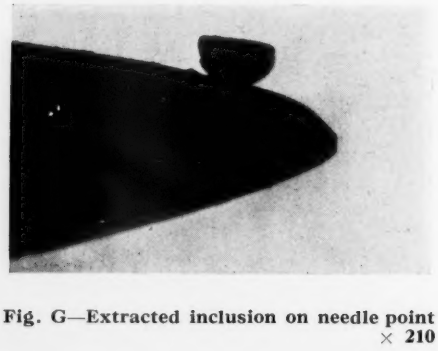

Fig. G—Extracted inclusion on needle point × 210

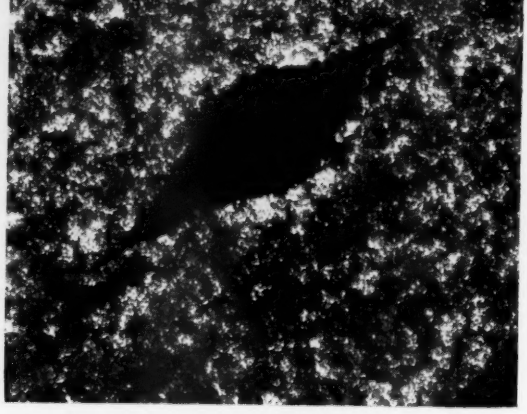

Fig. H—Surface cavity after extracting inclusion × 400

Dr. **J. F. Watkinson** (Fighting Vehicles Research and Development Establishment, Ministry of Supply): It is reported that the fracture in the higher tensile steels commences below the surface at an inclusion. It is difficult to accept the suggestion that the notch effect of an inclusion at the free surface of the specimen where the stresses are greatest should be less than that of inclusions below the surface. It is stated that all the specimens were polished with 00 emery paper prior to testing. Perhaps considerable compressive stresses may have been produced in the surface of these steels by this polishing procedure and this would transfer the point of maximum stress from the surface to some position below ?

Referring to Table XI, it is interesting to observe that the (fatigue limit)/(maximum tensile strength) ratio decreases in those steels heat treated to 110 tons M.T.S. This agrees with the results given by Gough *et al.*[1] Presumably the deterioration in the fatigue properties of these steels is due to non-relief of quenching stresses because the steels have been tempered at such low temperatures. In this connection the following results from a previous paper by Mr. Frith are of interest:

	Ni–Cr Steel	Cr–Mo–V Steel
Tempering temperature, ° C.	200	600
Max. tensile strength, tons/sq. in.	90·0	90·5
Fatigue limit (reversed bending), tons/sq. in.	±43·19	±43·26
(Fatigue limit)/(Maximum tensile strength)	0·48	0·48

In steels heat-treated to give 60 tons M.T.S., the (fatigue limit)/(maximum tensile strength) ratio is approximately 0·54. In the examples quoted, the two steels were heat-treated to give 90 tons M.T.S.; in the case of the nickel–chrome steel the quenching stresses would not be fully relieved by tempering at 200° C. but in the other steel, tempering at 600° C. should have removed these stresses. It is interesting, therefore, to note that the ratio was reduced to 0·48 in both cases. This suggests that some factor other than quenching stresses is responsible for the reduction in this ratio as the tensile strength increases.

The scatter in these results is much greater than that in the results presented by Gough *et al.*[1] and Frith.[2]

According to the report, two polishing procedures were used (*see* pp. 15 and 23). In the first method, steels were turned and then successively polished in the same direction through different grades of emery to 00 paper; I suggest that the surface is buffed, not polished, by this procedure and that the distorted surface is perpetuated rather than removed. In the second method, the specimens were finish ground and then polished with 00 emery paper; in these specimens the high tensile stresses produced by grinding might well persist through the subsequent polishing operation and lead to scatter of the order found in Table XIV*a*, where in several cases the life at ± 50 tons is greater than that under ± 45 tons/sq. in.

A polishing procedure which has given consistent results[3] imitates the method used in preparing specimens for metallographic examination; the radius specimens after form-turning are polished alternately longitudinally and laterally with 1½, F, FF, emery cloth, IM, IF, 0, 00, and 000 emery paper.

CORRESPONDENCE

Dr. **J. L. Robinson** wrote: I am mainly interested in the results obtained with carbon-chrome bearing steels and the conclusions that Mr. Frith has drawn from these.

The question of the type of inclusion affecting fatigue life is of major importance. If we assume that the manganese sulphide type of inclusion, of the size normally encountered in well-made O.H. steel is relatively harmless ('general conclusion' No. 5), then not only have many casts of steel been rejected unnecessarily, but also large numbers of finished bearing races. If it were possible to distinguish the harmful from the comparatively harmless type by macro-examination of the track surface, and more important, those in the highly stressed sub-surface zone, it seems reasonable to anticipate an increase in the life expectancy of very highly stressed bearings and at the same time to obtain a lower rejection rate of finished rings.

Rig tests made with highly stressed roller bearings having long alumina-type inclusions on the track surface, and others with inclusions of unidentified type but similar size, have shown that failure usually commences elsewhere than at the marked place, and that by the end of the test all evidence of the surface inclusion has disappeared.

Such results appear to confirm Mr. Frith's suggestion that only a certain type of inclusion leads to a reduction in the expected fatigue life.

The use of a fatigue test as part of the specification for very highly stressed steels appears to be quite feasible.

I have had the pleasure of co-operating with Mr. Frith for several years on the fatigue testing of bearing steels, and can confirm that there has been a satisfactory degree of agreement in the results obtained in our respective laboratories when using samples from the same part of an ingot. Also, an equally satisfactory agreement has been obtained with the laboratory of the steel supplier and it is perhaps of interest that agreement in the fatigue test is better than in the inclusion rating.

Mr. **J. Clayton-Cave** and Mr. **T. R. Allmand** (B.I.S.R.A.) wrote: The use of the term 'Fox count' by Mr. Frith in connection with the inclusion counting which he reports for the steels heat-treated to 60–110 tons/sq. in. U.T.S. is open to criticism. It is well known that a Fox inclusion count involves the examination of a certain number of fields at a given magnification, representative of the complete ingot section after reduction by forging or rolling to a specified diameter, namely 1⅜ in. Bolsover[4] describing the method suggests that variations of magnification, size of bar, etc., can be made, and will give the same inclusion number provided sufficient of the section is examined.

The sections used for inclusion counting in the work reported by Mr. Frith are stated to have been cut from Wöhler-type fatigue test-pieces, presumably those shown in Fig. 2, which have a maximum diameter of 0·500 in. Furthermore, these test-pieces were cut originally from the outside portions of a 5-in. gothic bar, as shown in Fig. 1, and it is, therefore, difficult to see how an inclusion count on such a sample can be representative of the whole ingot section. Various workers[5, 6] have shown that the size of bar, as indicating the amount of reduction from the ingot, can appreciably affect the result of an inclusion count, and this is understandable. In consequence it is difficult to accept the allocation of a Fox count number to an inclusion count made on samples representing only a small percentage of the total ingot cross-section and that after a reduction to only 5-in. gothic bar.

Mr. Frith claims that the inclusion count obtained on these samples is in good agreement with the count provided by the suppliers. Whilst there is no information in the paper on how the suppliers made their count, it is reasonable to suppose that they did so on the 5-in. gothic section, as there is no mention of any other bar size, e.g. 1⅜-in. dia. If this was so and assuming that the suppliers' count refers to the whole cross-section it is surprising that the two estimates agree so well.

If the above criticism is valid, the statement that there is no relationship between the Fox inclusion count and fatigue limit of these materials cannot be accepted as proved.

We would agree wholeheartedly with Mr. Frith's comment that a method of inclusion counting which gives a numerical value to a combination of type and size and, one might add, shape, would be a great help in assessing the influence of inclusions on fatigue properties.

With reference to the initiation of fatigue fractures at inclusions just below the surface of the specimens, in the steels heat-treated to 100 tons/sq. in. or 750 D.P.N., it may be of interest to report a rather spectacular example that has been found in a rejected experimental cast of 1% carbon–chromium steel heat-treated to approximately 750 D.P.N.

Longitudinal specimens taken from $\frac{3}{8}$-in. rolled bar were tested by Wöhler two-point-loading rotating bending machines. The specimens were found to fail with a fracture containing a conspicuous white spot, as shown in Figs. 3–6 of Mr. Frith's report. Each white spot also contained a dark area usually located at the centre or near the centre, as depicted in Fig. 4 of the report. However, on examining the dark area at higher magnification, it was observed that the dark spot was caused by the presence of a prominent spherical inclusion which was firmly attached to one half of the specimen, leaving a corresponding cavity in the other half of the fracture. Figure *D*, taken with oblique illumination, depicts the type of inclusion found in several of the fractured test pieces. It can be clearly seen that the inclusion is standing proud of the surface of the fracture and throwing a shadow on to the fracture. Figures *E* and *F* show the same inclusion under bright- and dark-field illumination but at a higher magnification. A cross-section shows the inclusion to be firmly embedded in the matrix and to be only slightly elongated in the direction of rolling.

The nature of the inclusion has not yet been firmly established, but from its general appearance, its reaction to polarized light, and its hardness (approx. 650 D.P.N.), it appears to be of a siliceous type.

Our colleague, Dr. B. C. Woodfine, has demonstrated that tensile tests carried out on 1% carbon–chromium steel, heat treated to 750 D.P.N., also give fractures showing a white area, containing a dark spot. It has not so far been possible to locate an inclusion attached to one half of the tensile test-piece but examination of the cavities in both halves suggests that an inclusion could have been present which was probably pulled out or shattered when the test-piece fractured. In view of this it appears that this type of fracture is characteristic of fracture in very hard materials rather than a phenomenon specifically caused by fatigue failure.

AUTHOR'S REPLY

Mr. **P. H. Frith** wrote: I would like to thank the various speakers for their kind remarks about the paper. In reply to Mr. Wilcock, I consider that the fatigue results he gives to illustrate the scatter on the 750-D.P.N. steel are abnormal, but on the other hand I agree that more scatter will be experienced on this type of steel than on a steel of lower hardness. Regarding the use of a test at ± 55 tons/sq. in. for specification purposes, although this is suggested in the paper, we have at Bristol had this test in our specification for a number of years. When it was first included the tests were carried out in our laboratory. After a short while tests were carried out in our laboratory, in the ball-race manufacturers' laboratory, and in the steel suppliers' laboratory. The results of these tests showed, as stated by Dr. Robinson, that a satisfactory degree of agreement was obtained between the three laboratories, when using samples from the same part of an ingot.

Regarding the second point raised by Mr. Wilcock, no discussion is given in the paper on the application of the 750-D.P.N. fatigue results to ball races, because this would have entailed an appreciable lengthening of the report. However, I did make a few remarks on this subject in the presentation of the paper, by stating that at least three requirements are important for ball and roller races which are highly stressed:

(i) The fatigue resistance should be as high as possible

(ii) Inclusions which are present should be small and uniformly distributed. This is necessary to prevent a high rejection rate being obtained on the finished machined bearings, when tested by magnetic-particle methods using both the current-flow and magnetic-flow techniques, and or by binocular inspection of a suitably etched surface

(iii) The hardness and structure should be such as to obtain a minimum amount of wear.

The tests in this present investigation showed that acid or neutral O.H. steels generally satisfied the first requirement. When these types of steel are accepted by fatigue and metallographic tests, it has been shown that the second requirement is also frequently obtained. The third requirement can only be assessed by rig tests. No claim is made that fatigue tests can replace rig tests, but it is suggested that fatigue tests may be a useful sorting test of material prior to rig tests. Fatigue tests can also be carried out far more quickly than rig tests, and therefore appear to be a more useful acceptance test for a predetermined type of steel.

The results given by Mr. Wilcock in Table *A* do, I consider, confirm the conclusions given in my paper. These results show that the fatigue properties obtained for basic electric-arc steel are more variable than for acid O.H. steel. The results given by Mr. Wilcock in Table *B* also appear to confirm my results, although I must admit that Table *B* gives a higher proportion of high-fatigue basic electric-arc steels than in my report. However, Table *B* does show that the fatigue properties of this type of steel are greatly influenced by the steel-making method, and for these eight casts only four passed the suggested specification requirement of 5×10^6 cycles at $\pm 55{\cdot}0$ tons/sq. in. The last cast (*H*3782) had very low fatigue properties, and as fracture was obtained at $1{\cdot}5 \times 10^6$ cycles at $\pm 45{\cdot}0$ tons/sq. in., I would not expect a fatigue limit above $\pm 38{\cdot}0$ tons/sq. in. for this material. This value is about the same as the lowest obtained in my report.

In reply to Dr. Sutton, the paper by Ransom and Mehl was not available when I wrote my report, but I agree that the results are most interesting. I have not so far been able to examine Ransom and Mehl's results, although it did appear from my work that the percentage reduction due to testing in the transverse direction was different for equiaxed than for columnar crystals. The majority of my work was carried out solely on the latter type of crystal structure, but higher transverse fatigue limits, and therefore lower percentage reductions were obtained by Woolman, for equiaxed crystals on steels of over 100 tons/sq. in. U.T.S.

The results given by Mr. Bardgett on a 67 tons/sq. in. U.T.S. steel after nitriding are very interesting and show, as stated, that the effect of the inclusions diminishes with section size. In my report the specimens for the 60 tons/sq. in. U.T.S. steels were obtained from 5-in. gothic bars, and for the 750-D.P.N. steels from bars which were mostly less than 1 in. dia. The machine described by Mr. Bardgett for testing ball-race steels should be very useful, and the results may assist in determining the effect of the fatigue properties on

bearing 'life.' I would suggest that before the test Mr. Bardgett should examine his specimens by the current-flow and magnetic-flow techniques to determine the standard of cleanness. Binocular inspection of a suitably etched surface before testing would also be useful. By these means a comparison of the surfaces prior to test would be obtained, and any inclusions detected could be marked, to determine if they initiated the failure.

In reply to Professor Austin, I agree that further work is necessary to check and prove or disprove some of the results in my paper. However, at present I do not anticipate being able to pursue this subject any further, as the practical results which we required are now available. No doubt other laboratories will be carrying on this work, when the points raised by Professor Austin will be examined. Also the points raised by Dr. Allen are extremely interesting and should help future investigators on fatigue. No doubt as he suggests, steels with even higher fatigue limits will be obtained in the future, and these improvements will be at least partly obtained by eliminating weak spots in the material. At present it appears that for reversed bending stresses, higher fatigue limits may be obtained by producing a compressive stress on the surface of high-tensile steels by nitriding. These steels would require a high value for the ultimate tensile stress after tempering above 550° C., which is about 50° C. higher than the nitriding temperature.

In regard to Mr. Ineson's first question, I consider that the method used to assess the fatigue limit is satisfactory, bearing in mind the main object of the work. This was to determine the effect of different methods of steelmaking on the fatigue properties, and small differences below 5% were not regarded as significant. The microradiographic specimens were obtained from the Wöhler fatigue test-pieces on completion of the test, to ensure that they were as far as possible representative of the material tested, and in general one specimen was obtained from each test piece examined.

The results given by Dr. Cina on the effect of cold working (as obtained during polishing) on the amount of surface-retained austenite are most interesting. In my paper no attempt was made to give the actual percentage value of the austenite on the surface, but the intensity of the austenite lines was given as weak, very weak, etc. However, as austenite was detected on the surface of some specimens by this test, it appears that even though the polishing may have reduced the amount as suggested by Dr. Cina, it did not eliminate it. The magnetic saturation values were regarded as a better measure of the amount of retained austenite, as this test measured the amount through and along the critical section of the test-piece. The effect of grain size on the fatigue properties of the En 31 material was not examined, but whilst I agree that grain size has some effect on fatigue properties, I doubt if it would account for more than a small part of the differences obtained between the electric and O.H. steels.

In reply to Dr. Watkinson, I do not consider that fracture occurred below the surface, due to compressive stresses produced during polishing, for the reasons stated on pp. 84 and 120 of my report. The polishing procedure used for the specimens was carried out by hand and the surface was definitely not a buffed one. The grinding operation for the 750-D.P.N. specimens was very carefully carried out to minimize the surface tensile stress.

I was interested in the remarks made by Dr. Robinson that rig tests appear to confirm my conclusion that only certain types of inclusions are detrimental to fatigue. I was also very pleased to know that after operating a fatigue test in our ball-race specification for a number of years, Dr. Robinson considers that it is quite a feasible test, and that the agreement in fatigue results between three laboratories has been satisfactory.

In reply to Mr. Clayton-Cave and Mr. Allmand, 'Fox' inclusion counts were originally made by the various members of the Committee in the standard way. After further discussions it was decided to make further counts on samples obtained from the Wöhler fatigue specimens, as it was thought that these results would be more representative of the material tested. This I still consider was the correct procedure to adopt. The spherical inclusion observed by Mr. Clayton-Cave and Mr. Allmand at the beginning of the fatigue fracture in a rejected cast of En 31 material is very interesting. This inclusion was similar to those found in our tests, in that it had not deformed to any appreciable extent during rolling, and appeared to be of the siliceous type. It is interesting to note that white areas similar to those previously found on fatigue test-pieces have now been observed on tensile test-pices of En 31 material heat-treated to 750 D.P.N. The mode of formation for these white areas may or may not be the same as for the fatigue specimens, and therefore I do not think it can be stated at present that this type of fracture is characteristic of fracture in very hard materials. This type of fracture was obtained in our fatigue tests on steels heat-treated to 80 or 110 tons/sq. in. U.T.S., which cannot be described as very hard materials.

During the preparation of the report, further work was carried out to try and extract a spherical inclusion. Numerous specimens were prepared by hand polishing and etching with a 10% solution of bromine in methyl alcohol. This slowly etched the steel and loosened any inclusions on the surface. The inclusions appeared bluish after this etch and could easily be distinguished from the smoothly etched surface around them. When sufficiently loosened it was possible by pressing on to one side of the inclusion with a needle point, to revolve it in its cavity and finally eject it. Such an inclusion is shown in Fig. *G*, whilst Fig. *H* shows the cavity remaining after the inclusion had been extracted.

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JOINT DISCUSSION ON THE LENGTH OF FLAMES AND O.H. FURNACE PREHEAT

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parentheses):

"The Length of Oil and Gas Flames," by *A. L. Cude* (1954, vol. 176, Mar. pp. 270–273).

"Measurement and Influence of Preheat in the Open-Hearth Furnace," by *W. P. Cashmore* (1954, vol. 178, Oct., pp. 112–121).

Mr. **A. L. Cude** (formerly with B.I.S.R.A., now with I.C.I. Billingham Division) presented his paper.

Mr. **W. P. Cashmore** (Guest Keen Iron and Steel Co., Ltd.) in presenting his paper said: Since submitting this paper, I have come across some interesting German work. An investigation was carried out by Bansen[1] to determine the effect of checker temperature on working rate and production. These temperatures are probably more closely related to preheat in Germany, where more care is taken to minimize heat losses and infiltration, than is the case in Britain. The conclusions were that a 100° C. increase in checker temperature gave about a 9% rise in working rate and a 16% reduction in fuel consumption.

Also, to increase production during the war, the effect of firing coke-oven gas directly over the outgoing regenerator was investigated.[2] There were two burners over each regenerator, the four at the exhausting end being supplied with coke-oven gas and air; the latter was preheated to 600° C. by a recuperator heated by the waste gases in the flue. This auxiliary heating was intended to prevent the usual drop in checker temperature during fettling and charging caused by the opening and closing of doors. It was unfortunately not possible, probably because of wartime conditions, to carry out comprehensive preheat measurements during the trials, but some measurements carried out suggest that the increase in preheat lay between 150° and 200° C.

Figure *A* shows the effect of the supplementary heating of the regenerators on the working rate of a 70-ton furnace. The increase resulting from the supplementary heating was about 16%, which suggests that the increase in working rate for an extra 100° C. of preheat was about 8–10%.

The importance of these results lies in the fact that they establish that preheat is an independent variable, since they show that when a deliberate change in air temperature was made, a corresponding change in working rate resulted. I believe that similar work was done in this country, but I am not aware of the results.

Our results indicate a rather lower increase in working rate for an increase of 100° C. in preheat than is found by other workers, and it is interesting to examine the reason for this. The probable explanation is that the other work was carried out in Germany and in America, where the slag bulk is about 50% of that usually carried in this country. Why this should affect the results is not clearly known, but it is obvious that the beneficial effect of an increase in the temperature difference between the flame and the bath would be reduced as the slag bulk increases, because of the enhanced insulating effect.

Mr. **R. Barber** (Land Pyrometers Ltd.): My comments will be restricted to Mr. Cashmore's paper. The author's work will almost certainly inspire others to try similar experiments, and this is therefore an opportune time to emphasize the dangers of using inaccurate suction pyrometers. In the past, pyrometers comprising only a single radiation shield surrounding the thermocouple sheath have been used. We now know that these are quite inadequate and probably operate at less than 50% efficiency, which means that when the suction is turned on, the indicated temperature will change less than half way to the true gas temperature. The author has shown that temperature changes of more than 200° C. are observed in uptakes when the suction is turned on (cf. Fig. 9); the single-shield pyrometer will therefore indicate a temperature more than 100° C. in error. A second, and probably more important, fact is that a 50° C. change in temperature of the surroundings will have the same effect on the pyrometer as a 50° C. change in gas temperature. It is therefore dangerous to report results of this type without very careful consideration and the early results of Hallíday,[3] which the author mentions, may be deceptive. Even a pyrometer with two refractory shields is far from ideal and if the shields get dirty an efficiency of only 70% may be obtained.

Table *A* shows[4] the need for multiple shields particularly at high temperatures. These theoretical results are determined for black metal shields through which the hot-gas velocity is 500 ft./sec. If lower velocities are used then each shield becomes equivalent to less than one shield at 500 ft./sec. and, for example, at 100 ft./sec. each shield will be equivalent to 0·5

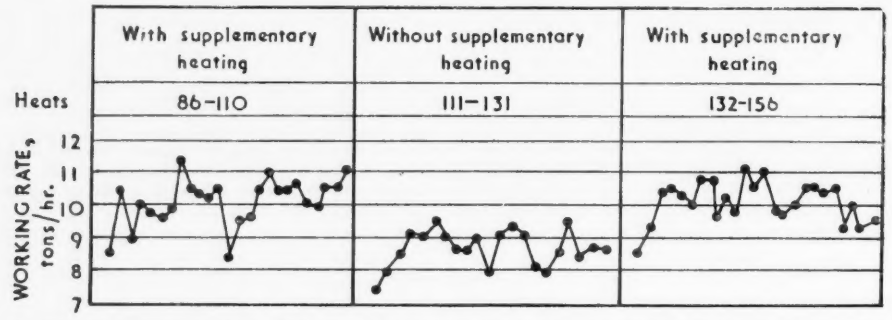

Fig. A—Effect of supplementary heating of checkers on working rate of an O.H. furnace (after Engels[2])

Table A

EFFICIENCY, %, FOR SHEATHED THERMOCOUPLES WITH BLACKENED METAL MULTIPLE RADIATION SHIELDS

Temperature, C.	Number of Radiation Shields									
	1	2	3	4	5	6	7	8	9	10
400	98									
600	88	98								
800	71	93	98							
1000	54	81	93	97	99					
1200	39	69	85	92	95	98	99			
1400	28	55	74	83	91	95	97	99	99	
1600	20	43	62	73	83	90	94	96	97	98

shields at 500 ft./sec. Table *A* shows that at low temperatures one or two shields are adequate, but to obtain reliable readings at preheat air temperatures five or six metal shields and a gas velocity of 500 ft./sec. are needed. Refractory shields are more efficient than black metal shields, because of their lower emissivity, so that a refractory shield, when new, may be as efficient as two or two and a half metal shields. It must be stressed, however, that the increased efficiency is due almost entirely to the low emissivity; consequently, if refractory shields become dirty and their emissivity increases, they will not be much better than metal ones.

Marsh[5] in the U.S.A. chose an adequate system of five metal shields for uptake air-temperature measurement and his results should be quite accurate. Mr. Cashmore has used the Schack system of an outer refractory tube packed with a ring of smaller tubes. If the gas can pass freely round all the available surfaces the accuracy for clean tubes should be at least as good as Marsh's. If the spaces between the small tubes and the outer tubes are blocked with cement the efficiency will be less than the five metal shield unit.

The author's choice of a criterion to indicate the accuracy of his readings is not altogether wise. He chooses the criterion of doubling the suction and noting the drop in indicated temperature. The validity of this depends very much on the difference between the temperature of the gas and the surroundings. If this difference is 200° C., stating that the drop should be less than 10° C. will be adequate and will indicate that the readings will be in error by about 20° C.; but if the difference is 100° C. or less (as Fig. 9 indicates is the case at higher preheats) it is impossible to get a change as large as 10° C. by doubling the suction, no matter how inefficiently the pyrometer is working, and the criterion is therefore of no value.

Suction pyrometers for measuring preheated air temperatures should comprise at least three refractory shields or their equivalent (e.g. the Schack arrangement) mounted either inside or outside a water-cooled probe, and should use a hot-gas velocity of about 500 ft./sec. If this is done, a simple method of determining the accuracy of the pyrometer during a set of readings is to *halve the velocity* of the gas and note the change in indicated temperature: the magnitude of this change will be equal to the residual error of the pyrometer at full velocity. The change due to halving the velocity must be less than one-eighth (preferably one-tenth) of the change when the suction is turned completely off.

When the results for the very interesting Fig. 9 were obtained showing the observed difference at different preheat temperatures between the suction-pyrometer readings with suction on and suction off, did the author block the exit of the pyrometer when he switched the suction off? I have had very peculiar results when omitting to do this, as there may be sufficient positive pressure in the uptake to blow enough hot gas through the pyrometer to enable it to be operating at 30–40% efficiency when it is thought that no gas is flowing.

I was very interested in the design of the pyrometer used by the author which is obviously very convenient for his particular application where a water-cooled jacket can be permanently installed in the uptake wall. Does he ever encounter difficulties due to the slagging up of the probe inside the jacket or due to the distortion of the jacket, which makes the removal of the probe awkward?

Mr. **R. W. Evans** (Steel Company of Wales Ltd.): I have a deep-seated conviction that preheat is one of the most important factors influencing the efficiency of modern O.H. furnaces. Marsh by his work at Bethlehem has shown that for 100° C. extra preheat he reckoned to get 16% increased production. Mr. Cashmore mentions 10%.

Historically, the importance of preheat has been partly recognized, because over many decades a large number of patents have been taken out for different designs of checker work and checker brick, and there was no doubt that that work aimed at getting the furnace to work faster, even if people did not know quite why it happened, and keeping the checkers on the outgoing end of the furnace reasonably free.

If increased production or an increased working rate is obtained from a furnace with a high air preheat, it is important to consider exactly where that increase comes. I submit that it comes largely during the melting and not during the refining period. The effect of the higher preheat is to give a higher flame temperature, which results in increased speed of melting scrap. I cannot see that an increased speed of refining should be expected, but, as the author says, one should expect a lower fuel consumption during refining. I believe that the major benefit, however, is to be expected during the melting operation. Have the increased speeds which the author has found with increased air preheats in fact been associated with charging and melting, and not with refining? One corollary would be that tilting furnaces which use up to 80% of hot metal, compared with 50% in a fixed furnace, might expect less benefit, because they use less scrap and have to melt less.

With regard to the German work mentioned by the author, those furnaces were fired by mixed coke-oven and blast-furnace gas, and if the hydrocarbon and methane content of the coke-oven component of their mixed gas was low, they needed, in order to keep the furnace working efficiently, to keep the checker temperatures up, to crack the hydrocarbons and give luminosity to the flame. That may have seemed to the Germans to be a very important factor. In that respect, does the author know the increase of temperature in preheat which was associated with this additional firing of the checker work?

The author has referred also to the part which is played by the slag pocket and the uptakes of the furnace in giving increased preheat. That must be very important, because these are, after all, the hottest parts of the furnace, and when the air finally goes up the uptake it is going up a relatively very highly heated section of the furnace. We can picture a twin uptake as two very large checker apertures which air goes up at fairly high velocity, and we would expect it to take up some heat. It has been said that an O.H. furnace can be worked with no checkers at all, and I believe that it has been done, which shows that the wall temperatures of the regenerator and slag pocket and

uptake can be relied on to give enough preheat to work the furnace.

We must try to perfect a suction pyrometer which will give us not only a spot reading but also an accurate reading not over 24 hr. or a week but also over the whole campaign of the furnace, because I believe that the indications which such an instrument could give would be of overwhelming benefit to the operator of an O.H. furnace. Such things as the incipient blocking up of his checkers or the beginning of air infiltration or other matters which affect speed of working or the flame temperature of the furnace would be immediately noticed, instead of the furnace tailing off and the operators wondering what is the matter. With a suction pyrometer they could see at once that there was something wrong, and they might be able to take steps to put it right.

It seems from Fig. 1 of Mr. Cashmore's paper that the effect of blow is more pronounced in the second part of the campaign than in the first. What is the reason? I should like to know also what was the effect of some of the significant drops in preheat, e.g. on 14th Feb. and 21st Mar., sometimes over a period of weeks, and why this should happen.

Having said that charging is the most important aspect, I should like to add that it is most important to know also what the preheats are during the charging period, and not so much during the refining period, although the author takes the preheats during the refining period as the data on which to plot these curves. If in fact the preheat during the charging period is associated with that during melting, it is important to know from furnace to furnace to what extent the preheats during charging and melting can be improved.

The author has taken two furnaces of similar capacity, one with double uptake and one with single uptake, and he says that for equal preheats the single-uptake furnace works on an average 0·4 tons/hr. faster than the double-uptake furnace. For both, 100° C. extra preheat gives an additional figure of 0·5 tons/hr. The double-uptake furnace works with 50–100° C. higher preheat than the single-uptake furnace. Why, under these conditions, does the single-uptake furnace work faster than the other?

Mr. **R. Mayorcas** (B.I.S.R.A.): I am glad of this opportunity of speaking on a subject which is justifiably arousing a great deal of interest in all the O.H. steel-producing countries. It is important in any investigation of productivity that the approach is correct and I believe that although Mr. Cashmore has made a very real contribution to the study of air preheat (he has mastered the technique of furnace experimentation) his approach has not been entirely correct. The German work he referred to shows a different approach to this subject but one which Mr. R. W. Evans pointed out was taken for a very special reason and one not applicable in most of our circumstances.

Let me first assure the meeting that I agree entirely with the importance of air preheat and that a 100° C. extra temperature on the air preheat must be worth having and is likely to increase the output of a furnace. However, an extra 10° C. on the maximum roof temperature can also have this effect and it has often been shown that an increase in the fuel properly burnt in the furnace will lead to an increase in output. Therefore, in a system such as the open-hearth, wherein almost everything is interrelated, a mere plotting of one thing against the other is not enough to prove cause and effect, even when relationships of significance levels 1 : 1000 appear from the exercise. What we really want to know is how to obtain a 100° C. extra preheat and then when we know how to turn it on or off at will, what effect this change in variable has on the output of the furnace.

Consider the curves which the author has obtained for average weekly outputs and average fuel per ton against average air preheat. The scatter is large in all cases, namely 10½–13½ tons/hr. and 26–36 gal./ton for a change of preheat from 1120° to 1310° C. In spite of this scatter there is a strong correlation but it has required 33 points to show this. Therefore, measurements made over a single cast are going to be useless for guiding a manager and I submit that no manager is going to wait for 33 consecutive measurements to be made before he is going to diagnose that the checkers are becoming blocked! That is why I believe the approach used by Mr. Cashmore here and Mr. Marsh in America is wrong and the right approach is the one being taken by B.I.S.R.A. through the Steel Practice Committee and its Instrument Sub-Committee, namely, can we find ways of changing this variable of air preheat by a given amount and, when we can, what change does this have on output? In the research we must always remember this: a manager wants two things from his checkers, (i) high preheat, (ii) long life. It is no good having a preheat of 1500° C. for two weeks if on the following week the furnace is out of action. B.I.S.R.A., therefore, are studying the problem of cleaning the waste gases in properly designed slag pockets and uptakes so that advantage can be taken of better designs of regenerators which will be more efficient with the higher velocities. Such regenerators will last longer and give more highly preheated air.

Mr. Cude and others in B.I.S.R.A. have shown us, with simplified equations, the relationship between what happens in a burner and what happens to the flame. It is interesting to use their formulæ to see what happens in a typical case. Take a furnace working at 200 gal./hr. with a given steam/oil ratio. Now, whereas the steam/oil ratio is changed in the refining period when the fuel rate is reduced, it is not often realized that if it is desired to increase the fuel rate from 200 to 235 or even 250 gal./hr. the same steam/oil ratio is not then good enough, because to get the same flame length, which may be the important factor in furnace operation, a greater steam/oil ratio is required. If the steam/oil ratio were 7 lb. per gallon of oil for the 200 gal./hr., then at 235 gal./hr. 10 lb. of steam for every gallon of oil would be required to give the same flame length.

If the same steam/oil ratio of 7 lb./gal. is maintained for the higher fuel rate the flame increases by about 3 ft., which in a small furnace is a big change and can lead to serious damage to refractories.

Mr. **S. G. Williams** (Guest Keen Iron and Steel Co., Ltd.): As Mr. Cashmore has pointed out, these investigations really started owing to some remarks of mine. Our experiences at Cardiff when we introduced oil-firing may perhaps emphasize the importance of air preheat. As most people in the steel trade are aware, we at Cardiff were among the first in the country to adopt 100% liquid-fuel firing. Our first attempt was remarkably good; in fact, it is only on few occasions that we have equalled the performance we then obtained, for as time went by the results deteriorated and we could not determine the reason for this.

We had practically no preheat measurements at this time, but we noticed that the deterioration was accompanied by a falling away in checker temperatures. Mr. Cashmore was asked to investigate this matter, and he has proved, without any shadow of doubt, that air preheat is one of the most important factors in the operation of an O.H. furnace.

There is still a great deal to be learned regarding the factors controlling preheat. One speaker has

asked how we get the higher temperature. There are several factors. First of all, it is necessary to have good combustion. Not always, although your waste-gas temperatures may be high, is the preheat high. You have to pay attention, as a previous speaker stated, to the distribution of the waste gases over the cross-section of the checkers. Unless the fantails of the uptakes are so designed that an even distribution is obtained, the preheat will be reduced, since the incoming air may not come into contact with the brickwork which has been heated to the greatest extent by the waste gases.

Again, the quality of the brick is important. We know from experience at Cardiff that with new checkers a comparatively small fluctuation in the temperature of the top course of checker brickwork obtains due to reversals. However, as the brickwork deteriorates the fluctuation gets bigger and the preheat drops. We think this is because the heat transferred from the waste gases to the air is stored only in a comparatively thin layer of slag over the surface of the brick, so that the brick itself experiences virtually no temperature fluctuations.

Furthermore, the author has repeatedly proved to us at Cardiff that infiltration has a very bad effect on regenerator performance. We have had checker temperatures up very high, whilst the preheat has been very little, if at all, above the checker temperature. Under these conditions, we have always found that when this infiltration has been eliminated, the preheat has increased, with benefit to the furnace performance.

As Mr. Evans has pointed out, another important factor regarding the air temperature is the pick-up of heat by the incoming air in the slag pockets and uptakes.

He has asked to what we attribute one furnace working better than another for the same preheat. I do not know the exact answer; all I can say is that there must be better combustion in the furnace, not due to air temperature but to the flow pattern of the incoming air around the flame. This I consider to be most important.

Mr. **G. G. Thurlow** (B.C.U.R.A.): I should like to sound a note of caution concerning the assumption, made by Mr. Cude and now so commonly used as to be almost axiomatic, that the rate of combustion is purely a function of mixing. Some evidence has recently been obtained at B.C.U.R.A. which suggests that this is not strictly true in a fuel bed, and I am not happy about its being applied indiscriminately to all flames, especially the highly turbulent ones now being brought into use.

Regarding the wider aspects of Mr. Cashmore's paper, the whole question of the measurement of temperature and heat content of the preheat and waste gases is of supreme importance in so far as these readings can give, irrespective of flame emissivity, temperature, convection (live or dead), etc., the essential data on how much heat is being actually liberated in the furnace. To quote Dr. Sarjant and Mr. Mayorcas, this is the primary criterion of how much heat flows into the bath.

It should be emphasized that the heat content of the gas in B.Th.U.s per cubic foot is the basic factor here, although temperature is the quantity usually quoted. This is satisfactory when talking about sensible heat but needs further consideration if total heat is required. The effect of the latent heat of the moisture is probably well enough appreciated. The moisture in the preheat passes through the system without change of state and does not have much effect, but the steam injected and moisture formed during the combustion added, in the case of one oil-fired O.H. furnace, about 60 and 140 B.Th.U. per lb. of dry gas, respectively, to the sensible heat of the waste gas: this is equivalent to the sensible heat produced by a change in gas temperature of about 100° and 250° C. respectively.

It has been suggested that two other factors could conceivably have an effect on the total heat of the waste gas, viz. dissociation and the heat content of the dust, both of which are rather unknown quantities. We have recently carried out, however, some trials on an O.H. uptake where we compared total heats on both preheat and waste gases as estimated from corrected temperature readings taken with the Land-B.I.S.R.A. completely cooled suction pyrometer, with the equivalent values measured directly by calorimetry, using a modified form of the total-heat meter initially developed at the B.C.U.R.A. by Dr. Baulk. The agreement between the two methods was excellent, and we have no reason to doubt that total heats evaluated from temperature measurements (if these can be made accurately) are reliable, at least up to 1500° C., which was the highest temperature recorded.

Whilst we would not advocate the use of the total-heat meter for use in the range of temperature and other conditions where the suction pyrometer can be successfully employed, it worked so well during these trials with regard to speed of response, consistency of reading, etc., that it is an instrument worthy of consideration for further use at temperatures and conditions, such as in the waste gases, where suction pyrometry is less easy.

Mr. **J. W. Till** (John Summers and Sons Ltd.): Mr. Cashmore is to be particularly congratulated on his development of an instrument for measuring air preheat under the arduous conditions of steelworks operation. His technique is good, because it ensures a fairly rapid correction of any discrepancy which may arise in his apparatus.

With regard to the furnace, the author has given data for the differences between a single-uptake and double-uptake furnace. From these figures it seems to me that, while there is a difference in preheat, there is not a significant difference in output. Figure 3 shows the higher pick-up obtained with a double-uptake furnace, and we have a higher preheat and lower fuel consumption for approximately the same output rate as the single-uptake furnace. I presume from the figures and the relationships drawn from them that they were obtained from these furnaces during one campaign. If in view of the heavier groupings of points in certain parts of these graphs we calculate an average figure for preheat, does the single air intake still show a faster working rate? Is that still found when one average figure of preheat is taken for the whole of the build of a single- or double-uptake furnace?

Another point arises from the assumption that the figures in Fig. 3*b* are those for one campaign on a single-uptake furnace: do they include the values for the first week and for the last three weeks of the build, as shown in Fig. 1? Figure 1 suggests that the preheat is lower during the first week, while the heat reserve builds up in the checkers, and that it falls off during the last three weeks, perhaps because the draught is failing. Does the author think that the relationships which he plots will still hold good if these points are excluded from the graph? The drop of about 300° C. in preheat in the last three weeks is a rapid falling off. Is it due to checkers blocking up and causing either a difference in rate of heat transfer or is it increased air infiltration drawing more air through the uptake walls and port-end brickwork? In view of the statement that the metered air was kept almost constant, can he tell us what amount of air was carried and what was the fuel rate during the

(i) (ii)

Fig. B—Ceramic inserted cylinders: (i) old design; (ii) new design

refining period, and whether he carried the same fuel rate and the same air on both furnaces ?

The author refers to metallurgical factors and their possible effects. My organization is always interested in sulphur and we wonder whether these values are affected by the problem of sulphur removal. If they are, then they will probably be adversely affected. If the figures are adversely affected by sulphur removal, has the author made any attempt to correct the figures for a prolonged refining period caused by sulphur removal ?

He tells us that it is difficult to draw any firm conclusion from blowing these furnaces, and that is borne out in Fig. 1. Any interpretation can be applied to those preheat temperatures. Has he found any difference in his constant temperature at the top of the checkers if the filling is changed from a 6 in. × 6 in. to a 9 in. × 9 in. or similar chimney-type flue without transverse openings, or by a change in the type of fuel, e.g. oil, tar, or either of them with gas ?

Mr. Evans mentioned the amount of hot metal used in the tilting furnace. Has the author found any difference in the pick-up of preheat from charging to refining periods by altering the amount of hot metal charged into the furnace ?

I am very glad to see the attempt to standardize the method of obtaining a preheat figure for a reversal. How much would a mean figure taken on reversal differ from his calculated figure ? As Mr. Mayorcas has said, B.I.S.R.A. are doing work on these preheat determinations, and their figures for the value of preheat during reversal are arrived at by a different method. At John Summers our results have not yet reached a stage at which useful comments can be made, but our curve differs from the author's because we do not show the sudden initial drop. That may be due to the inertia of the thermocouple or to furnace conditions, but we do have a different shape of curve. I suggest that those interested in the measurement of preheat temperatures should get together and correlate these methods if possible.

Mr. **G. Wellensiek** (Metallurgical Engineers Ltd.): The idea of the suction pyrometer is to prevent the thermocouple giving out heat by radiation to colder parts of the furnace, or at least to reduce this by increasing as much as possible the rate of convective heat transfer on to the thermocouple; in addition, a large number of shields between thermocouple and furnace put an obstacle to its radiating off heat to furnace. Therefore, accuracy of reading and recording increases with the number of shields and with flow velocity.

Out of this idea Schack developed in 1931 a ceramic inserted cylinder shown in Fig. *B* (i); a new design is given in Fig. *B* (ii). According to the above theory one cannot expect the same accuracy of reading as with the old design.

However, the new design is very often used nowadays in Germany, because it is cheaper and pyrometers do not become dirty so quickly as hitherto. Readings taken with this simplified design and published in German technical periodicals are therefore not too accurate. Mr. Barber has pointed out the relationship between accuracy of reading and the number of pyrometer shields.

Mr. **A. B. Pritchard** (Shell-Mex and B.P. Ltd.): Can Mr. Cashmore elaborate on the steps which were taken to raise the preheat temperature from 1130° to 1350° C. on the *D* furnace, and similarly on the *E* furnace, or were these variations normal with the ageing of the furnace, as indicated in his Fig. 1 ?

In the last paragraph on p. 113 he mentions definite action being taken, but no indication is given of the relative effect of spraying the port ends or increasing the checker capacity. Is it possible to give a value in terms of air preheat to either of these modifications ? The further remarks in this paragraph, linked with Fig. 7, seem to indicate that with the same metered quantity of air it was found possible to burn in one case just over 6 gal./min. and in another just under 3½ gal./min. In other words, it was possible in the first case to burn 75% more oil than in the second. Presumably the metered air was adequate for 3½ gal./min., so that the infiltration at the higher figure must be equal to 75% of the metered air. Would it be more fundamental to label Fig. 6 as being a comparison of fuel consumption against air infiltration ?

I should like to renew my quarrel with Mr. Cude. When he presented his earlier paper,[6] I suggested that he had overlooked the effect of the quality of atomization when he deduced his equation for flame length and applied it to oil. In his present paper he says on p. 270: " Since a close similarity of behaviour between gas and oil flames was found in the earlier work, it was considered unnecessary to repeat this investigation with oil." At that time I suggested to him that he had used one type of burner which was a very good burner from the point of view of atomization, and he may have been a little rash in attempting to base all his conclusions with regard to oil firing on the results obtained from a good atomizer. I again suggest that the equation should include a constant which is dependent on the quality of atomization, the type of liquid fuel being burnt, the temperature of the furnace, and possibly the type and quality of the atomizing medium. From my experience a good burner, operating under very similar conditions in every respect, will give a much shorter flame with a distillate fuel as compared with a heavy residual fuel, especially if the latter is not heated adequately. Does the author think that his equation would be true for different atomizing media ? For instance, if the atomizing medium was changed from air to steam or coke-oven gas, could the flame length be calculated from the formula, assuming that everything else was equal ?

CORRESPONDENCE

Mr. **S. H. Brooks** (United Steel Companies Ltd.) wrote: Mr. Cude is to be congratulated on his efforts to give a general solution to this problem, and the inclusion of data for various flame temperatures and limited excess air should make the results applicable to practical cases. I cannot help feeling, however, that whilst the entrainment into a jet could be calculated, the composition of the entrained fluid could vary from pure air to pure waste gas, and hence similar jets could

give completely different results in combustion chambers where the degree of recirculation was markedly different. In other words, does not the flow pattern play an important part in the determination of flame length ?

Despite this criticism, such formulæ are very useful for obtaining comparative results to show the effect of changing the fuel or nozzle size, etc. For instance, if a cold CO gas burner with a nozzle diameter of $2\frac{1}{2}$ in. gives a flame length of 25 ft. (assumed), the length of mixed-gas flames—gas preheated to 600° C., nozzle diameter of 5 in.—can be calculated:

CO in gas, %	29	38	50
Flame length, ft.	8·3	10·2	12·6
Decrease (cf. cold CO gas flame, $2\frac{1}{2}$ in. burner), %	67	59	50

Even if these results are not strictly accurate they do show the dramatic decrease in flame length that would result from burning preheated mixed gas in a 5 in. dia. burner.

To revert to the formula presented in the paper, an attempt has been made to apply it to the case of a back end steam atomized heavy fuel oil burner with 3000 lb./hr. oil and 1800 lb./hr. dry saturated steam. The pressure behind the convergent $\frac{13}{16}$ in. dia. nozzle was 100 lb./sq. in. absolute.

If it is assumed that the pressure in the nozzle can be calculated from the accepted value of the critical pressure ratio (57·7 lb./sq. in. absolute), q, s', and u can be calculated for this pressure and substituted in the equation. This gives a flame length of 28 ft. When corrected for the high flame temperature of O.H. practice the length becomes 32·4 ft. and if a further correction is applied for limited excess air (say 20%) the calculated flame length comes out at 45·4 ft.

This latter value seems excessive and perhaps Mr. Cude would care to comment on these calculations ? If the pressure in the nozzle were lower than 57·7 lb./sq. in. absolute, as it might be expected to be since energy will be consumed in accelerating the oil droplets, then a more reasonable answer might be obtained, but how are such adjustments to be applied to the formula presented ?

Much research has recently been directed towards improving the efficiency of steam–oil burners so that greater inspiration can be produced with less steam. Whilst great advantages can undoubtedly result from this work, I feel that much more consideration could be given to the well-known advantages of multiple burners. If n burners are used with the same total nozzle area as a single burner the flame length could be reduced by $1/\sqrt{n}$ or, with the same flame length and hence reduced size of the multiple nozzles the amount of steam used could be reduced by $1/n$. Hence, with only two burners the flame length could be reduced by 30% or the steam could be cut down to half with the same flame length. It is suggested that the potential performance of multiple burners is far better than might be obtained by any improvements of a single burner and that more effort should be directed towards using multiple burners in O.H. furnaces.

It is of course essential that the individual flames do not interfere with each other as otherwise the full benefit will not result. Could Mr. Cude give any indication of the spacing necessary on, say, an O.H. furnace ?

Following this line of thought, it would seem reasonable to suppose that a slit type of nozzle would give greater entrainment than a circular one, owing to the higher surface/volume ratio, although it is suspected that this type of jet would soon become round again. Has Mr. Cude any experience of jets other than circular ones and what are his views on this possibility ?

Mr. **P. D. Sunavala** (Department of Fuel Technology, University of Sheffield) wrote: The form of Mr. Cude's equation for flame length indicates that the use of steam for atomizing should give a shorter flame than the use of air because of its lower density. On the other hand he stresses the importance of the rate of mixing of fuel and air in determining the flame length. One would, therefore, expect the air atomizing burner, in which part of the air is premixed with the oil, to give the shorter flame. Can Mr. Cude explain this apparent contradiction ?

AUTHORS' REPLIES

Mr. **A. L. Cude:** In reply to Mr. Pritchard, I agree that my published work refers only to an air atomized burner, but I have since had several opportunities to apply the flame length equation to both air and steam atomized burners using heavy fuel oil and I have found good agreement. These observations were made in furnaces operating at temperatures in the region of 1400° C.; possibly, at the lower intensities of radiation found in other types of furnace, the relative rates of evaporation of different oils would have a noticeable effect. Heavy fuel oils would then give a longer flame than light oils.

The equation should be applicable to a burner using coke-oven gas as the atomizing medium, but it would be necessary to allow for the additional air needed to burn the coke-oven gas. This could be readily accomplished by referring the calculation to 1 lb. of fuel oil and adding the air needed to burn the corresponding quantity of atomizing gas to that required by the oil. This would give the effective value of r_t to substitute in the equation.

I have no real quarrel with Mr. Pritchard concerning the importance of atomization. The burner I used in my original work was undoubtedly a very good atomizer and I do not consider that my equation could be applied to a much inferior atomizer. However, poor atomizers continue to be plentiful in spite of the many difficulties which arise from their use. It is to be hoped that the constant efforts of the oil companies to encourage better oil burning practice will result eventually in the disappearance of bad atomization.

Regarding Mr. Brooks's comments, dilution of the combustion air with recirculating waste gas will certainly increase the flame length as this increases the total amount of gas which must be entrained to burn a given quantity of fuel. The increase in length will be proproportional to the increase in total flow rate in the flame.

The flame length equation is not easily applied to the type of burner usually employed on the O.H. furnace because the characteristics of two-phase flow are not sufficiently understood to allow an accurate estimate of the jet momentum. Fortunately the range of operating conditions found in the O.H. furnace is fairly small and the following approximate form of the equation seems to provide a fair estimate of the flame length: $L = (220\sqrt{A})/R$, where R is the steam/oil ratio, lb./lb., and A is the nozzle area, sq. ft.

Using this equation and allowing for the effect of restricted excess air, the estimated flame length for the conditions quoted by Mr. Brooks is 33 ft., which certainly seems more reasonable than the value obtained by using the original form of the equation.

The use of multiple burners seems to be a very simple way of increasing the quantity of fuel burnt in a given space. A spacing of about one-sixth of the total flame length, say 5 ft. for an O.H. furnace, is ample.

A flat flame burner would offer some advantages but nothing of this nature appears to have been tried. One of the earlier forms of oil burner was fitted with an

elliptical nozzle but this had no apparent effect on the flame shape. There is an industrial gas burner on the market which gives a ' batswing ' flame and which has so far been made in sizes up to 40,000 cu. ft./hr. capacity, but nothing of a similar nature appears to exist for oil.

In response to Mr. Sunavala's question it is quite true that the use of steam for atomizing increases the flame length in proportion to the increase in the total flow associated with a given mass of oil. The quantity of steam used does not usually exceed about 5% of the total of oil and combustion air so that the effect is small compared with the momentum changes which may be found under certain conditions. The statement that the use of steam gives a shorter flame than the use of air is only true if both the mass flow rate of the atomizing medium and its pressure at the burner are the same in each case. The steam jet will then have a higher velocity and the greater jet momentum gives the shorter flame.

These conditions imply different sizes of burner, but in practice it is more usual to retain the same size of burner and the same atomizing medium pressure. Under these conditions the mass flow rate of the atomizing air is greater than that of steam and compensates for the lower velocity of the air jet. The jet momentum is then approximately the same for both air and steam so that similar flame lengths are obtained. Allowing for the diluting effect of the steam, the air atomized burner will give a slightly shorter and hotter flame.

Mr. **W. P. Cashmore:** I am very interested in the criterion suggested by Mr. Barber to determine whether the instrument error is within acceptable limits; unfortunately, he does not mention whether it is based on a theoretical discussion, or has been determined experimentally. With regard to peculiar readings obtained when the suction is switched off, we too have noticed that cold air can under certain conditions be drawn into the uptake via the pyrometer; we have included a valve in the suction line to remedy this (*see* Fig. 8). No difficulty in retracting the probe has arisen from either slagging of the probe or distortion of the water jacket.

It is difficult to estimate how the benefit of a given increment of preheat is affected by different proportions of hot metal; as far as I know, no work has been done to investigate this point. Since it appears that the beneficial effect of higher preheat lies in the increase it effects in the temperature differential between the flame and the bath, it is to be expected that the greater the average temperature of the charge during a heat, the greater is the benefit of a given increment in preheat. Thus, I would expect increasing the preheat to have a considerable effect in a cold-charged furnace, but an even greater effect as the percentage of hot metal increases, since the average temperature of the charge throughout a heat would also be greater.

Similar considerations seem to apply to the relative effect of preheat during charging, melting, and refining. On the basis of this argument, benefit will be obtained during charging, but the maximum benefit during refining. However, these remarks are largely speculative.

Mr. Evans has suggested that the increased working rate obtained on the German furnaces mentioned was due to the thermal cracking of the methane arising from the higher checker temperatures and the resulting higher flame emissivity. That this was a factor to be taken into account was clearly recognized by those who carried out the experiments. It seems unlikely that the effect would be greater than that of carburetting pure coke-oven gas, and according to the information at my disposal, the latter would not have resulted in an increase in output of more than about 5%,[7, 8] whereas the observed increase was 16%. Thus, a substantial proportion of the increase is to be attributed to the increased preheat.

The increase in preheat due to the additional checker heating was measured by Prieur,[9] using suction pyrometers. He found it to be between 150° and 200° C.

I am heartily in agreement with Mr. Evans on the desirability of having a continuous measurement of preheat. Why it is that blowing the checkers is attended by varying degrees of success I cannot yet explain. It is obvious, however, that the result will be much affected by the type and quantity of build-up on the bricks, and also the brick temperature. An equally important factor might be the humidity of the compressed air !

We are also unable up to the present to pin-point the cause of fluctuations in preheat, but we are reasonably certain that the major factors are: (i) infiltration, (ii) slagging and blocking up of the checkers, and (iii) heat losses through the brickwork.

This would be roughly their order of importance. As a general guide, sudden fluctuations are due to (i), caused probably by cracks in the brickwork opening and closing with the expansion and contraction of the furnace, whilst trends over a long period are likely to be largely due to (ii). Some guide on the latter point can be obtained from a study of the temperature fluctuations within a reversal, since these increase appreciably as the checker slags up. The same effect is noticeable in connection with top checker brickwork temperature.

We have tried repeating our correlations using charging period preheats and have obtained substantially the same results. This is because the charging preheat differs from that obtained during the refining period by a practically constant amount for a given furnace.

Some general confusion appears to have resulted from my remarks concerning the single and twin uptake furnaces considered. They do in fact work at approximately the same rate, and the twin uptake furnace does have a preheat which is substantially higher than that in the single uptake furnace. The fact that the latter has a higher working rate and a slightly lower fuel consumption for a given preheat we attribute, after considerable investigation into the matter, to better flow patterns in the furnace laboratory. Indeed, we have based recent furnace redesigns on this assumption, with apparent benefit.

I was surprised to hear Mr. Mayorcas's condemnations of standard statistical techniques; however, I was able to include in my opening remarks some results obtained by other workers under conditions where the preheat was turned on and off at will. I am pleased to hear that he and his colleagues are going to try and find out how we may increase our preheats beneficially.

In reply to Mr. Till, the diagrams are based on results obtained over periods of more than a year in each case. We have carefully investigated whether the relationships we have determined are due only to well-known trends during the campaign of a furnace, and we are satisfied that they are not. The average air and fuel rates during refining would be 530,000 standard cu. ft./hr. and 340 gal./hr. for the *D* furnace, and 540,000 standard cu. ft./hr. and 340 gal./hr. for the *E* furnace.

It is generally accepted that sulphur pick-up from the flame is at least partially responsible for much of our sulphur trouble, particularly when low-sulphur steels are being produced. Since with a higher preheat, a lower fuel input will give the same heat input to the bath, it seems that high preheats would be of even greater benefit to furnaces making low-sulphur steels.

The effect of changing the flue size cannot of course be considered without reference to the intensity of loading of the checkers. Perhaps the simplest estimate of this is the ratio of the checker heating surface on each end to the hearth area for furnaces fired with rich fuel. Changing over from a 12 in. × 9 in. flue-type checker

to the type of 6 in. × 6 in. checker described in the paper gave us an increase of about 100° C. in preheat. The heating surface of the checkerwork at each end after the change-over was just over 40 times the hearth area. If the checker heating surface were very much higher than this, the change-over might have a negligible effect. Another important point would be the regenerative effect of the slag-pockets and uptakes relative to that of the checkers.

I heartily agree with Mr. Till on the need for standardization of techniques amongst those engaged in suction-pyrometry.

In answer to Mr. Pritchard, some of the changes in preheat were due to chance fluctuations, some to the slagging up of the checkers, and some to deliberate action, such as carefully spraying the furnace or blowing the checkers. However, we are confident that the relationships evolved are not merely a reflection of the influence on working rate and fuel consumption.

Mr. Pritchard points out that in Fig. 7, the fuel rate is altered considerably without the metered air being changed. If now it is assumed that the variation in preheat is caused by the infiltration of cold air, it will be found that the increase in fuel rate necessary to hold the bath at tapping temperature as predicted in Fig. 7 is such that the oxygen content in the waste gases will remain approximately the same, even if account is taken of the oxygen requirement in the bath.

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Correspondence on the Paper—

The Corrosion Resistance of Low-Alloy Steels*

By J. C. HUDSON and J. F. STANNERS

Mr. **Russell Franks** (Electro Metallurgical Company, Pittsburgh, U.S.A.) wrote: It is encouraging to note that the data presented in the paper by Dr. Hudson and Mr. Stanners on the low-carbon 3% Cr steels have confirmed those secured in the United States some years ago. These steels exhibited excellent resistance to corrosion under commercial atmospheric corrosion conditions and in sea-water. It is my opinion that these results are of extreme importance from the economic point of view in combating these two types of corrosion. The results obtained by Dr. Hudson and Mr. Stanners and those given in two U.S. papers[1, 2] are of sufficient importance to warrant actual commercial investigation of the low-carbon 3% Cr steels in applications in which either or both types of corrosion are involved.

Dr. Hudson and Mr. Stanners have carefully conducted a widespread investigation, and they should be complimented on the thoroughness with which they have tested the large variety of low-alloy steels. It is apparent that their results, like ours, showed that while the low-carbon 3% Cr steels corroded more slowly than the ordinary carbon steels, they simultaneously exhibited excellent resistance to pitting in sea-water, which represents an attribute lacking in many of the high-alloy steels. This point is emphasized in the summary table of the paper on corrosion tests in sea-water.[2] Further information on this point is given by LaQue.[3]

AUTHORS' REPLY

Dr. **J. C. Hudson** and Mr. **J. F. Stanners** (British Iron and Steel Research Association) wrote in reply: We are pleased to learn that our results for the corrosion resistance of 3% Cr steel are in substantial agreement with those of Mr. Franks. We agree with him about the possible industrial applications of this steel, and we understand that it has already been used by British engineers for such purposes as bolts in lock gates, where resistance to corrosion by sea-water is of particular importance.

We feel, however, that for structural steelwork exposed to the atmosphere, equally high corrosion resistance is obtainable from steels of lower chromium contents—e.g. of the 1% Cr, 0·5% Cu type. Moreover, although Mr. Franks's experimental work provides some reassuring evidence on the subject, it is clear that careful control of the carbon content is necessary to avoid air-hardening of 3% Cr steels, and this may not always be possible.

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Correspondence on the Paper—

The Sulphur Distribution Reaction Between Blast-Furnace Slag and Metal*

By J. TAYLOR and J. J. STOBO

Dr. E. T. Turkdogan (B.I.S.R.A.) wrote: After reading this paper most carefully, I found it very difficult to follow the authors' arguments, which seem to bear little relation to their own experimental work. The method adopted by the authors to interpret their experimental results is most confusing and, because of the unjustified assumptions made in the calculation of various activity terms, their conclusions are subject to criticism.

With reference to Fig. 3, it seems most unlikely that the activity coefficient of ferrous oxide in very dilute solutions (i.e. in blast-furnace-type slags) will deviate much from unity. However, it would have been better if the authors had tabulated the calculated ferrous oxide activities against composition instead of giving them in the form of Fig. 3, where the activity is not given in a conventional form nor are the standard states mentioned. Assuming, however, that Fig. 3 is not wrong, it would follow that Henry's law is obeyed; this contradicts the authors' statement in p. 364: "The results are shown as a_{Fe}/a_C *vs.* (FeO) in Fig. 3 and confirm that f_{FeO} does vary even over this restricted range."

Assuming, however, that the a_C/composition relationship calculated by Chipman[1] is correct, the extrapolation of the curves in Figs. 5*a* and *b* beyond the carbon saturation point is meaningless. What justification do the authors have in assuming that sulphur is equivalent to carbon for the effect it exerts on the activity coefficient of carbon? From the data of Kitchener, Bockris, and Spratt[2] it is possible to calculate the effect of sulphur on the activity coefficient of carbon at saturation, but these values of f cannot be used for melts at lower carbon activity (*see also* Turkdogan and Hancock[3]). In view of the lack of data on interactions of solutes in liquid iron containing various alloying elements, it is not possible to treat a set of results, such as those of the authors, thermodynamically without introducing unjustifiable assumptions.

The mechanism of sulphur transfer from metal to slag suggested by the authors is not experimentally distinguishable from that proposed by Chang and Goldman[4] and Derge, Philbrook, and Goldman.[5] The authors suggest that as a secondary step oxygen moves from metal to slag taking iron with it, yet deny the possibility that sulphur, in moving from metal to slag in the primary step, can also take iron with it. The similarity of oxygen and sulphur makes one believe that they would behave in the same way. Moreover, although the equation [S] + (O) = (S) + [O] represents conditions at equilibrium, there is no justification for assuming that it can give any guidance to the mechanism by which the equilibrium was reached. This phenomenon has been discussed more fully elsewhere.[6]

It should be borne in mind that molten iron containing large proportions of carbon reduces alumina dissolved in the slag. In fact, Morris and Buehl[7] found that at 1600° C. carbon-saturated iron kept in an alumina crucible in carbon monoxide at 1 atm. pressure contained 2·33% aluminium, as a result of reduction of the alumina crucible. At about 2% carbon, the contamination of the

* *J. Iron Steel Inst.*, 1954, vol. 178, Dec., pp. 360–367.

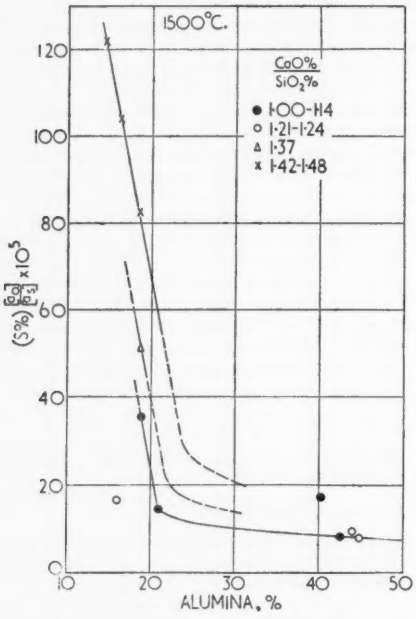

Fig. A—Sulphur capacity *v.* Al wt.-% for ranges of CaO/SiO_2 ratios at 1500° C.

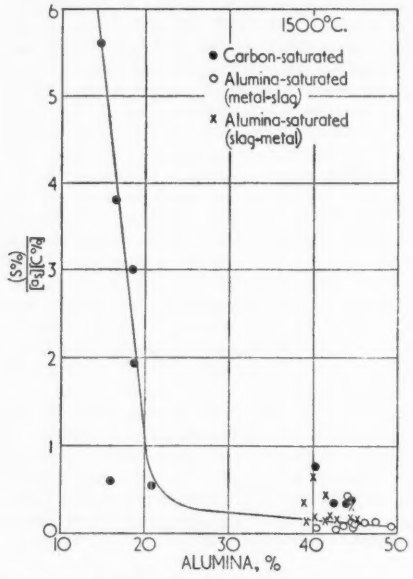

Fig. B—Sulphur capacity *v.* Al wt.-% for all melts at 1500° C.

melt by aluminium was reduced to about 0·8%. It would, therefore, appear that the authors' melts must have been contaminated with aluminium, particularly in those experiments where alumina-saturated slags were used. The presence of aluminium of the order of 1% is expected to have noticeable effects on the activities of sulphur and carbon.

I should now like to attempt to obtain certain relationships between slag and metal compositions from the authors' data. Consider the following expression representing the sulphur equilibrium between metal and slag phases:

$$[S] + (O) = (S) + [O] \quad \ldots\ldots(1)$$

As pointed out in detail elsewhere,[8–10] for a given temperature the sulphur capacity ($= (S\%)[a_O]/[a_S]$) varies only with the slag composition up to 1% sulphur in slag. In the present case the value of $[a_O]$ can be calculated only for melts saturated with graphite. From the free energy of formation of carbon monoxide from its elements in their standard states[11] and free energy of solution of oxygen in iron,[12] the following equations may be derived:

$$CO\ (g) = C\ (gr.) + [O]\ (1\%\ \text{activity}) \quad \ldots\ldots(2)$$

and

$$\Delta G^{\circ}_{T} = -1520 + 20{\cdot}38T \quad \ldots\ldots(3)$$

From the above expressions, the following is the temperature dependence of the activity of oxygen dissolved in carbon-saturated iron:

$$\log[a_O] = \frac{332}{T} - 4{\cdot}454 \quad \ldots\ldots(4)$$

Multiplying the ratio $(S\%)/[a_S]$, obtained by the authors, by $[a_O]$, computed from equation (4), the sulphur capacity can be evaluated. In Fig. *A* the sulphur capacity is plotted against weight per cent. of alumina for ranges of $CaO\%/SiO_2\%$ ratios for experiments at 1500° C.

Although this relationship is qualitatively in line with those discussed by other workers,[8–10] the authors should attempt to compare their results with those of Richardson and Fincham.[8, 9]

The above method of treatment cannot be applied quite so readily to the authors' other results (melts not saturated with graphite), because of the lack of *reliable data* and a *recognized* method of calculating the carbon activity in Fe–Si–S–C quaternary melts. Nevertheless, as a first approximation the sulphur capacity may be expressed as $(S\%)/[a_S][C\%]$, which is plotted in Fig. *B* against the weight per cent. of alumina for all the melts at 1500° C. The different basicities have not been differentiated in this diagram. The scatter of the points for melts saturated with alumina is partly due to the variation of the sulphur capacity with metal composition. It is interesting to note that the results obtained from metal → slag sulphur-transfer experiments are concordant with those of the slag → metal transfer experiments.

The grouping of the points in Fig. 4, leading the authors to a different conclusion, is believed to be caused by the unreliable method of calculating ferrous oxide activity. It is most unlikely that after 3–10 hr. the transfer of sulphur from slag to metal should not reach equilibrium. It was shown by Chang and Goldman[4] that heat of activation for the transfer of sulphur from slag to metal is 39 kcal./mol and that for the transfer of sulphur from metal to slag is 79 kcal./mol, indicating that slag → metal sulphur transfer should attain equilibrium more rapidly than the reverse reaction.

AUTHORS' REPLY

Dr. **J. Taylor** and Mr. **J. J. Stobo** (Royal Technical College, Glasgow) wrote in reply: The relationship between a_{Fe}/a_C and %FeO was checked with sulphur-free melts. It is true that the relationship over the range investigated is very nearly linear but not through the origin, and therefore it does not conform to Henry's law as suggested.

The authors do not assume that sulphur is equivalent to carbon but have used the data of Kitchener, Bockris, and Spratt to calculate the carbon equivalent of sulphur. There is no firmly established method of combining activity coefficients in multicomponent solutions, but the present method has been used with reservations by a number of authors.[12, 13] The present authors make similar reservations.

The grounds for the suggested sulphur mechanism are set out in the paper. Absolute proof in such cases is always difficult but maintenance of the FeO content of of the slag above that corresponding to equilibrium with carbon, whilst the corresponding sulphur equilibrium is established, seems to rule out the mechanism of Derge, Philbrook, and Goldman.[5]

As mentioned in the paper, a number of samples were analysed for aluminium with negative results.

The further discussion on the sulphur capacity of slags is of interest, but at the present stage it offers no advantage over that used by the authors, following Hatch and Chipman.

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LETTER TO THE EDITOR

A Note on Non-stoichiometric Vanadium Nitrides

SOME WORK has been carried out in these laboratories on the solubility of nitrogen in iron and its alloys.[1, 2] Although the experiments in the work referred to are capable of revealing the conditions for the formation of nitrides in iron alloys, they give no indication of the composition and constitution of the nitrides formed. A series of experiments is now being carried out on pure

nitrides to acquire more knowledge of the physical and chemical properties of various nitrides of metallurgical importance. This correspondence gives an account of the preliminary work on pure vanadium nitride.

The vanadium nitride was prepared by heating A.R. grade ammonium vanadate, in an alumina boat placed in a Kanthal-wound mullite tube, at 1100° C. for about 12 hr. in a stream of ammonia. The ammonia was dried, before entering the reaction chamber, by passing it over pellets of potassium hydroxide. At the end of the reaction period, the charge was cooled in the furnace whilst an ammonia atmosphere was maintained in the tube. The product, which was dark-brown in colour, was sieved and the −120 mesh fraction was used in the subsequent equilibrium experiments. This nitride contained 21·3% nitrogen, the remainder being vanadium, which compares well with that for the stoichiometric compound VN which contains 21·57% nitrogen.

All samples in this work were analysed for nitrogen by the Dumas method using 40–50-mg. samples; the results were reproducible within ± 0·1%. The vanadium was analysed by a volumetric method, which consisted of dissolving the sample in nitric acid, treating with sulphuric acid, and reducing the vanadium to tetravalent state by sodium sulphite in a CO_2 atmosphere; after complete removal of SO_2, the solution was cooled to about 80° C. and titrated with standard potassium permanganate solution to a pink end-point. The results were reproducible within ± 0·1%. In all cases the samples were analysed after the equilibrium measurements for both nitrogen and vanadium to make sure that the samples were not contaminated during the experiment, particularly with oxygen; the sum of the two elements was 100 ± 0·2%.

The purpose of this study was to determine the variation in composition of vanadium nitride with temperature under 1 atm. of nitrogen. Small samples of vanadium nitride (about 0·7 g.), prepared by the method already described, were placed in alumina crucibles and heated in a 1-in. dia. recrystallized alumina tube in a stream of oxygen-free purified nitrogen. The temperature of the molybdenum-wire-wound furnace was maintained within ± 2° C. of the required level. The temperatures were measured by a Pt/Pt–13% Rh thermocouple located at the base of the crucible and in close contact with it. At the end of the experiment the crucible and its contents were raised into the water-cooled top of the reaction tube to quench them; during this operation the flow of nitrogen through the tube was still maintained. It is regarded unlikely that the equilibrium established at higher temperature would be disturbed during rapid cooling. The preliminary experiments up to two days indicated that 24 hr. were quite sufficient for the establishment of equilibrium between the nitride and the nitrogen gas at 1 atm.

The results of these experiments were as follows:

No.	Temp., ° C.	N, wt.-%
1*A*	900	20·6
1*B*	900	20·2
2*A*	1000	19·7
2*B*	1000	19·5
3*A*	1100	19·7
3*B*	1100	20·1
4	1200	19·2
5	1300	18·8
6	1400	17·6
7	1500	17·1

Figure 1 shows that the original nitride corresponding almost to VN has lost nitrogen on heating in 1 atm. N_2.

A part of the vanadium–nitrogen phase diagram was investigated by Hahn,[3] who showed that in this binary system two nitride solid solutions exist. His phase-

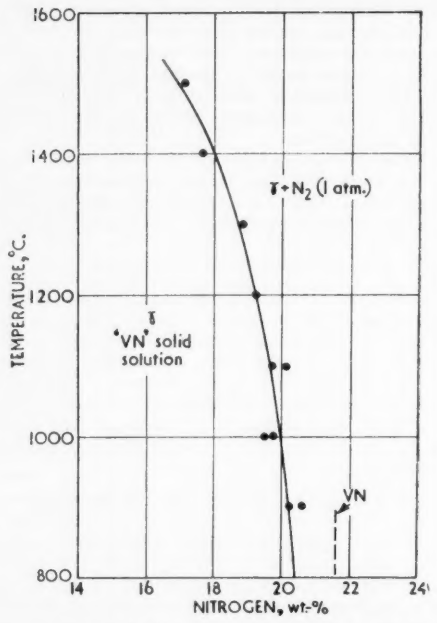

Fig. 1—γ-phase 'VN' solid solution in equilibrium with nitrogen at 1 atm.

equilibrium measurements at 1000° C. indicate that 'VN' (γ phase) is a non-stoichiometric compound with a homogeneity range from $VN_{1·00}$ to $VN_{0·71}$, i.e. from 21·6% to 16·4% nitrogen. This phase has a cubic structure of the NaCl type and its lattice constant decreases with decrease in nitrogen content: e.g. for $VN_{1·00}$, $a = 4·126$ Å., and for $VN_{0·71}$, $a = 4·064$ Å. From the present work it appears that in stating the high nitrogen limit of this phase it is necessary to specify the nitrogen potential of the system. Although $VN_{1·00}$ can be produced at 900–1100° C. in ammonia, on reheating in 1 atm. of nitrogen there is nearly 2% loss of nitrogen. A few X-ray powder patterns obtained on the authors' samples agreed well with those of Hahn.

The second nitride phase (β phase) identified by Hahn has a homogeneity range from $VN_{0·43}$ to $VN_{0·37}$, i.e. from 10·5% to 9·3% nitrogen. The β phase has a close packed hexagonal structure with lattice parameters $a = 2·835$ Å., $c = 4·541$ Å. at the upper phase limit and $a = 2·831$ Å., $c = 4·533$ Å. at the lower phase limit (lower nitrogen content). An attempt has also been made to prepare the β phase. This was achieved by heating a sample of the vanadium nitride in hydrogen for three days at 1500° C.; the specimen was then cooled to 1000° C. and maintained there in hydrogen for a few hours and then gas-quenched. The product contained about 13% nitrogen, the balance being vanadium. The X-ray powder pattern of this substance showed a few lines belonging to the hexagonal β phase, and the lattice constants calculated from them agreed well with those given by Hahn for the upper limit of the β phase.

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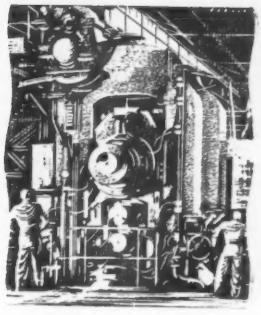
IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group



The Iron and Steel Engineers Group

Report of the Twenty-Seventh Meeting

THE TWENTY-SEVENTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4, Grosvenor Gardens, London, S.W.1, on Thursday, 9th December, 1954. Mr. W. M. LARKE, Chairman of the Group, was in the Chair.

At the MORNING SESSION, a paper by Mr. T. W. HOOD (Samuel Fox and Co., Ltd.), entitled "Practical Aspects of the Cold-Rolling of Narrow Steel Strip." (*Journal*, June, pp. 189–200), was presented and discussed.

At the AFTERNOON SESSION, the paper presented and discussed was "Wire-Drawing Machines for Steel Wire" (*Journal*, May, pp. 60–65), by Mr. H. RICHARDS (Marshall Richards Machine Co., Ltd.).

Discussion on the Paper—

Practical Aspects of the Cold-Rolling of Narrow Steel Strip

Mr. **T. W. Hood** (Samuel Fox and Co. Ltd.), in presenting the paper, said: This paper is based largely on the practice at one plant, which is not representative of one class of work, namely the bulk production of mild-steel strip. At our works mild-steel strip is mainly produced in the thinner gauges. My comments on pinch-pass reductions apply to this restricted range of thickness and not to the whole industry.

Output figures have not been given because much of the strip is in special quantities, of which the tonnage might be low but the value relatively high. It might be of interest on one special quality to say that we produce the equivalent of about 1500 miles a week of slit razor-blade strip.

On the question of the speed of the Steckel mill the average speeds are lower than those given, which refer to when the coil has built up to maximum diameter.

My remarks on the speed of Sendzimir mills refers to those rolling stainless steel, this being the application of this type of material with which I have been most concerned, but much higher speeds are used on other metals. With stainless steel the speed is generally kept down owing to the tendency to heat-streaking.

Since writing the paper I have received confirmation that soluble oil has for some time been successfully used on one of the earlier Sendzimir mills installed, in a plant which I have not visited.

In the paper I refer to one Sendzimir mill using tungsten carbide rolls; I have since been informed that they are also being used on a 37-in. wide mill.

Mr. **D. Reilly** (Guest Keen and Nettlefolds (South Wales) Ltd.): I visited the cold-rolling plant in Stocksbridge in 1951, and was very impressed by the neat layout and the high standard of plant cleanliness, which is essential to the production of fine-quality strip.

Plant size and quality of steel rolled vary so widely that it would be impossible to generalize about the practical aspects of cold-rolling. What Mr. Hood refers to as 'heavy gauge' we should call 'medium gauge,' and another section of the trade 'light gauge.'

The wide range of sizes and qualities of cold-rolled strip greatly influences the choice of rolling mill. It is necessary to make a compromise which covers the greatest range with the smallest number of mills.

The reasons for compromising are not fully understood; the rolling-mill theorist may think we are slow to adopt all the recommendations, and even users do not always appreciate that a good compromise for one plant may be bad for another. What represented a good compromise years ago may well have limitations to-day.

Mr. Hood quotes an example of reducing the loss in yield by allowing the back end to leave the reel after each pass. In the only example I have seen the gauges ranged from 0·64 to 0·128 in., and the mill speed was approx. 200 ft./min. No benefit would be obtained from a high-speed mill rolling thinner gauges; it is unlikely that the saving in scrap would compensate for the loss in output.

Mr. Hood also refers to a 4-high mill with 2·8in. dia. and another with 5½-in. dia. work rolls being used for pinch-passing mild steel. He also refers to 2-high mills with

10-in. and 12¾-in. dia. rolls being used for the same purpose. As research on the elimination of stretcher strains in mild-steel pressings indicates the desirability of using small-diameter rolls for tempering, would he comment on whether he can put this theory into practice ?

In view of surface requirements and the need to use the mill to the best advantage, the 2-high mill with large-diameter rolls is the best compromise for our range. Such a mill, without rolling lubrication, is not conducive to reduction, and the set-up is less likely to even out any gauge variation in the ingoing strip during temper rolling, with a resultant variation in hardness. The use of large-diameter rolls also minimizes the effects of skid when the mill is running light. A little difficulty when temper rolling wide widths and thin gauges is a penalty of compromise. In the mill of the future, roll gaps will be altered automatically so that any gauge variation in the ingoing strip will be maintained, in order that the final product may be consistent in hardness.

Variation in hardness is largely due to the variation of gauge. Automatic gauge control will minimize the variation, but it will not be eliminated. I am assuming that the annealed product is consistent in a coil.

Heavy tension can sometimes be used advantageously, and I appreciate the effect of tension in reducing the mill load. In our plant light tensions are deliberately used on the finishing pass. Much of the product is sent direct to annealing, and light tensions minimize sticking. On finer gauges, it minimizes the use of sleeves. When rolling very narrow widths, it prevents the distortion of the reel. In addition, the roller is conscious of the shape he produces, and so we have never favoured the 'T' method of automatic gauge control. The same trouble occurs with drums, because a wide range of thickness is covered ; a reel suitable for heavy gauges is unsuitable for thin ones.

The fact that 3 years elapsed before the tank of the central cooling system was drained for cleaning is presumably due to the fact that most of the rolling is intermediate and finishing rolling, rather than rolling from pickled strip. The volume of coolant in the main tank is double that of ours, and we change it every four months.

I should like to hear more about the magnetic rods and how much they contribute to extended life. Almost everyone who runs a high-speed reversing mill has had a similar experience to that as described by Mr. Hood, and in the absence of knowledge of the fundamental causes of spalling it has been mainly by the process of elimination that steps have been taken to deal with the set-up.

The hardness figures for our work rolls on the tandem mill compare favourably with those of Mr. Hood, but we have had to seek a compromise on the reversing mill ; we have gone down 5° scleroscope on the work roll and 10° on the backing roll.

We have a fixed sequence of roll changing. On the reversing mill the work rolls are changed every 8 hr. On the tandem mill No. 1 stand is changed every 32 hr., No. 2 every 16 hr., and Nos. 3 and 4 every 8 hr. All these roll changes are done during the meal time ; backing rolls in both mills are changed each weekend.

Grinding little and often has paid good dividends on spalling. The frequency of Mr. Hood's roll changes is commendable but he should change the backing rolls more often. Frequent changes would retard the appearance of small spalls.

Mr Hood's experience of increased temperature of the coolant is much in line with our own, which has risen to 120°C. ; we may try the increase to 150°C. which he has mentioned. Experience over a long period shows that the smaller the variation between the roll and the coolant temperature the better. I cannot fully appreciate the difference between soluble oil and mineral oil. We have a tandem mill beside the reversing mill, with a common coolant system. Rolls are never spalled on the tandem work roll or backing roll.

At one time there was a certain mill where, on the reversing mill, spalling of rolls was eliminated by offsetting the work rolls, a system which we adopted. I have never had a satisfactory explanation for this.

More thought should be given to the handling factors in all mills. Too often it is taken for granted that increased output is obtained by higher speed. More rapid roll-changing devices, better feeding facilities, better stripping devices for tandem mills, single-stand mills, and reversing mills are required in that order of priority.

We have always looked upon wipers as 'muck spreaders.' What are the advantages of a wiper and how long one lasts before changing ?

Mr. **Hood**: The economic justification for allowing the back end of the strip to leave the drum depends on a compromise between output and yield. For the mill in question, which is not at Stocksbridge, the output is given in the last paragraph of the section on hydraulically adjusted mills on p. 192 of the paper.

Choice of work-roll diameter for pinch passing, as referred to in the paper, is a matter of using available plant to the best advantage. The 4-high mills with small work rolls are used on very thin material; the 2-high mills are used on what we call heavy gauge and Mr. Reilly calls medium gauge. On certain classes of dead-soft steel a light pass is given to prevent the strip from kinking as it is unwound.

The suggestion to use an automatic gauge-control system working in the reverse sense from that normally adopted is very interesting. An argument can also be advanced for using a hydraulic mill, which can be made less stiff than a conventional mill and so reduce the variation of hardness due to variation of ingoing gauge.

Strip is not annealed in coils wound under the heavy rolling tensions mentioned in the paper, for, as Mr. Reilly points out, there would be trouble due to sticking. These tensions are only reached for very light gauges which, before annealing, are recoiled under light tension using fairly thin rims to avoid distorting the coil during subsequent handling. The roller examines his shape at the beginning of the finishing pass and can check it during recoiling.

The magnetic rods referred to consist of non-metallic tubes each containing a number of bar magnets. These tubes are arranged to form a horizontal grid a few inches below the surface, so that the soluble oil flows past them. Each weekend they are removed and the deposit of magnetic particles, which forms to a thickness of about ¼ in. round each magnet pole, is wiped off.

I do not doubt that Mr. Reilly is perfectly correct when he advises regular and more frequent backing-roll changing. As for the reference to a soluble oil temperature of 150° C., I must make it clear that this is much higher than has been tried at Stocksbridge.

On the question of offsetting work rolls on reversing mills, experiments have been made with varying amounts of offset on the high-speed reversing mills using white-metal work-roll bearings, to ensure that the bearing clearances were taken up in the same direction on all four roll necks as the white metal wore. This was mainly to overcome thrust-bearing problems, and no conclusions were reached on its effect on roll spalling.

The change to roller-bearings for the work rolls, as mentioned in the paper, was to avoid this bearing wear, and so minimize the amount by which the work rolls can become skewed and even crossed when rolling. This misalignment causes thrust and a variation of roll pres-

sure along the barrel which could conceivably affect spalling.

Strip wipers are used for several reasons. On the ingoing side they give back tension, which helps in controlling the strip during the first pass from an uncoiling stand. They also smear the rolling oil thinly and evenly on the strip; I have mentioned the use of rolling oil together with soluble oil. On the outgoing side they reduce the carryover of oil into the coil. They also collect metallic particles such as those occasionally breaking from the sheared edges of the strip, and from the brass side guides. Our wipers consist of $\frac{1}{2}$-in. pads, usually of felt, round which cotton blanket is wrapped. They are examined after each pass when finishing, and are changed several times a shift, the blanket being very easily replaced.

Mr. **P. L. Cowper-Coles** (Telektron (Great Britain) Ltd.): Mr. Hood rightly criticizes the mechanical measurement of continuous gauge control, owing to the time elapsing between passing through the rolling mill and the point at which the measurement of the thickness is made.

A simple system has been developed and is being used in Sweden for both measurement of the gauge and automatic control of the screwdown gear on high-quality cold-rolled strip. This equipment consists of a pneumatic continuous measuring device, which is coupled electrically to a pneumatic power unit for operating the screwdown gear. The measuring device used is an air-pressure-operated double-bellows mechanism, combining high accuracy with pointer torque, which stands up very well to the shock and atmospheric conditions existing in rolling mills. The power unit is a pneumatic diaphragm motor unit which operates the screwdown gear. This unit is very well suited to this application, as it starts with full torque and stops without overswing. The arrangement is designed for the tolerance required and the motor works step by step, which is arranged so that one step is less than the minimum change in roll setting desired. The cost of a control system like this is very much less than many of the electronic and complicated control systems now being developed and can be arranged to give remarkable accuracy.

Does Mr. Hood consider it would be wise in the case of light-gauge rolling mills to study the potentialities of this method, even though it does not offer a general solution to the problem of roll setting and gauge control in all its ramifications?

Mr. **Hood**: I have seen such a system in Sweden and agree that this method is worthy of study. It is somewhat similar to the system described in the paper, which is also not a general solution but was required to give high accuracy at reasonably low capital cost.

Mr. **C. W. Starling** (B.I.S.R.A.): The speed of the Steckel mill, depending on the build-up, will vary at least 100%. Has that any effect on the gauge?

In regard to the hydraulic mills, could Mr. Hood give some idea of their stiffness in relation to a normal mill? Does the roller have to change the pressure considerably to alter the gauge slightly?

Fabric bearings seem to have several advantages on the work rolls of the 4-high mill. They will run satisfactorily on soluble oil, so eliminating seal trouble when soluble oil is used as coolant. Does the fact that Mr. Hood's fabric bearings charred mean that he used an old-fashioned fabric? Modern fabrics run to 80° C. (which is higher than his proposed new coolant temperature) fairly satisfactorily.

Increasing the accuracy of gauge by making very stiff mills is only satisfactory up to a certain limit. The stiffness of the mill is governed by both the roll flattening and the mill stand. On a normal 4-high mill of the type Mr. Hood uses the roll flattening is between one-third and half of the total mill spring, and this cannot be eliminated by stiffening the housing. The real answer appears to be an automatic gauge control system.

We are doing work on the mechanics temper rolling, keeping in mind the possibility of making a soft mill with automatic control of tempering.

We have offset rolls and run with them straight, without any perceptible difference. On the other hand, we have not rolled enough material to get roll spalling, so we cannot say whether there is any connection.

Rolling under tension complicates the handling of coils. Has Mr. Hood considered putting bridle rolls on the outgoing side and driving them to apply tension to the strip?

The pneumatic system of automatic gauge control, in common with any direct measuring system, is difficult to apply. The point of measurement is at a distance from the rolls, and the thickness in the gap may not be the same as the thickness at the point of measuring.

Mr. **Hood**: As the Steckel mill uses an elongation meter with hand-measurement to check final gauge, the actual gauge variation along a coil is difficult to measure directly. The nearest data I can give are that on a small reversing mill with 4-in. dia. rolls, when taking a 10% reduction on 0·008-in. high-carbon strip, raising the speed from 200 to 600 ft./min. caused a reduction in gauge by 0·0003 in.

The modulus on the small hydraulic mills is about 1700 tons/in. This is comparable with but slightly lower than I would expect for an equivalent mill with mechanical screwdown.

Had we pursued the use of fabric work-roll bearings we should, no doubt, have found a material which overcame the difficulty mentioned. As explained in the paper, the use of soluble-oil-lubricated bearings was abandoned and we did not experiment with oil-lubricated fabric because roller-bearings offered a more positive solution.

Driven bridle rollers have for some time been used on temper mills, but have not been tried at Stocksbridge. For the finishing mills, the idea offers the possibility of being able to roll on collapsible drums (probably on sleeves) and so avoid the recoiling operation.

Mr. Starling rightly points out the difficulty of automatic gauge control using a direct measurement of strip thickness on the outgoing side. Nevertheless, it is a workable system and, for example, I have seen such an arrangement with stepped control of screwdown motors using the signal from, in this instance, a recent type of pneumatic gauge located on the delivery side.

In this connection, the accuracy and freedom from drift of the gauge is most important; the contact type of flying micrometer is still the type most widely used, with trials being made of the newer pneumatic, radiation, and other gauges.

Mr. **J. D. Dunlop** (Armstrong, Whitworth (Metal Industries) Ltd.): The first cold-reduction mill I was concerned with had been using backing rolls with hardness up to 70° Shore, and was by that time down to 65° Shore. I recently saw at a tinplate mill a backing roll that was substantially below 50° Shore, successfully rolling light-gauge stock which had been considerably work-hardened. To avoid work-roll spalling, relatively soft backing rolls might be of interest.

Mr. **Hood**: I have not made any tests on the influence of backing-roll hardness on the frequency of work-roll spalling. The backing-roll modulus of elasticity, and so the flattening and maximum stress in the work roll in the region of contact with the backing roll, would be little affected. Possible work-roll damage due to backing-roll roughness might be reduced, but there would be more rapid backing-roll wear.

In my experience, study of backing-roll hardness has

been directed towards improving the life of the backing rolls themselves.

Dr. **L. N. Bramley** (B.I.S.R.A.) : The association have been trying for some time to produce hot-rolled strip which is roughly parallel, and we think we have the cheapest answer. However, we have not yet been able to measure satisfactorily the gauge of the strip. We have produced not a fully automatic hot-rolled strip thickness meter but a programme controller. Hot-rolled strip, when it comes to the cold roller, is tapered, and there is a fair amount of repetition in the taper profile, and so without going to the elaborations of automatic control, we thought a large amount of taper could be taken out by putting in pre-set control. We have since developed such a pre-set programme controller which has now been in use for two years. When the strip can be measured, there will be a continuous plot of thickness. This can be used as a basis for putting in a reasonable programme and a large amount of troublesome taper on the hot strip will, we hope, be removed.

Mr. Hood's mention of the stability of closed-loop systems prompts me to say that the Plant Engineering Division is now fully equipped with the necessary equipment to take a harmonic response (feedback transfer locus) test on strip mills and any other piece of equipment, which is the only way to get a quantitative idea of how to stabilize a closed-loop control system.

Mr. **Hood**: The hot strip mill with which our company is associated is looking into the possibility of using an isotope gauge for measuring and displaying the variation of thickness as the strip leaves the mill, as a step in the right direction.

When a 30-ft. slab is in the furnace it is difficult to control the temperature accurately along the length. Most of the gauge variation appears to be due to temperature variation.

Mr. **H. O. Bradshaw** (Tube Products Ltd.) : Automatic gauge control will help the customer a great deal. Has Mr. Hood considered combining the controls, using the ingoing flying micrometer as a forecaster ? He could correct short-period variations in advance of the actual rolling time with the ingoing unit and use the outgoing flying micrometer, operating with a suitable delay or under-correction, to smooth out long-period variations. The two feedback loops (one contained by the other) could probably be made stable and still work effectively.

Mr. **Hood**: This is an interesting idea and one which we have indeed considered, so far without attempting to put it into practice.

Mr. **P. M. Martin** (Richard Thomas and Baldwins Ltd.): I should like to ask Mr. Hood three questions. Firstly, it would be of interest if he could make some general remarks on his cambering practice, particularly in relation to roll spalling. Does he employ a simple or compound camber ?

Secondly, has he ever employed one parallel roll operating with a roll having double the normal camber ? If so, what advantages has he found ?

Thirdly, to what accuracy does he estimate that he can measure roll camber ? Does he make a practice of taking roll camber by means of a suitable instrument, and if so can he give details of the type of instrument used for this purpose ?

Mr. **Hood**: Our roll camber is related to strip shape and not to consideration of spalling. A simple camber is generally used; indeed, on the high-speed mills, cambers are so small that the difference between simple and compound camber would be barely measurable. An exception is when rolling thin hard strip much narrower than the rolls—not a regular occurrence—when an appreciable camber over the working width is rolled off into a slight taper to prevent the ends of the rolls coming into contact. Backing rolls are parallel, except that on the two mills with smallest work-roll diameters the centre part (about one-third width) is flat and the ends taper slightly.

A combination of one cambered and one parallel roll is used on several mills, but mainly for ease of roll grinding where the total camber is small. Maximum normal camber is 0·002 in. full, ranging down to 0·0005 in. hollow, with several mills using parallel rolls.

By using a hand micrometer with suitable gap, I would say that the difference in diameter between two places on a roll barrel can be measured to about 0·0001 in. on our work rolls at room temperature, few of which exceed 6 in. dia. This accuracy applies only to relative and not to absolute roll diameter.

We do not take roll-camber records, though on much larger rolls this is done at a works with which we are connected, using a Gilbertson-Thomas instrument.

Mr. **Reilly** : There is much doubt in relation to the various theories of simple and compound cambers. We have tried them all, and the more compound the camber the more spalling occurs.

During the running-in period of a reversing mill, it was common practice for the work rolls to be cambered and the backing rolls ground with a corresponding concavity. Spalling of rolls was very frequent, and, as a last resort, these backing rolls were taken out and ground parallel. When these rolls were put into the mill, the operators, who instinctively come down a certain amount on screwdown in order to effect certain reductions, could not operate the mill. We found that, whereas in applying the full load to the mill a certain job required seven passes, we did it easily in three.

Then an order was accepted which was thinner in gauge than the mininum gauge rolled on the mill. Clean backing and work rolls were mounted and we were successful in doing that job. Five weeks later, when trying to do a similar job, we could not reduce it, and we remembered the effect of concave backing rolls. The backing rolls were removed and the rolls were checked; they had definitely gone concave. When clean backing rolls were put into the mill, the strip in question was reduced as easily as when we first attempted it. The object of changing backing rolls more frequently is to eliminate any concavity and thereby save the roll. I should change the work rolls with the backing rolls; it is a development to have very rapid roll changing.

Mr. **Hood**: We do not grind backing rolls concave, but with 19 mills in the main bay it is difficult to change backing rolls as frequently as Mr. Railly recommends. His comments on backing rolls wearing concave and so affecting spalling may have a bearing on an epidemic of work-roll spalling some time ago. To try to find which of the six similar mills were mainly responsible, work rolls were allocated to individual mills. Few spalls occurred, which from Mr. Reilly's experience might have been due to our ceasing to use work rolls at random with backing rolls all worn to slightly different shapes. After over a year without serious spalling trouble this system was abandoned to ease the problem of roll grinding: work rolls are changed not on a time cycle but according to pass cycle and roll marks.

Another epidemic came two years after that mentioned, but allocating rolls this time had no effect. Unfortunately, I have no records of backing-roll concavity to analyse on this problem, and so cannot say whether there is any substance in this theory.

Mr. **Reilly** : On the question of epidemics, do you not think that may be the main contributory cause ? Spalling of the roll is seldom coincident with its cause. The benefit of the change can only be judged by how it applies to a completely new set-up of rolls, When you make a change there may well be spalling, not because

of something done at that time, but because the work roll has been considerably weakened by being forced into the concave backing roll.

Mr. **Hood**: It was because we realized that spalling could originate long before failure, i.e. in any of the mills in which a roll might previously have been used, that we decided to allocate rolls to individual mills. On certain rolls we attempted to detect incipient spalls before each grinding by ultrasonic examination, but without success. An apparently sound roll might spall when next used.

Discussion on the Paper—

Wire-Drawing Machines for Steel Wire

Mr. **H. Richards** (Marshall Richards Machine Co., Ltd.) presented his paper.

Mr. **R. S. Brown** (Rylands Brothers Ltd.): Mr. Richards is to be congratulated, first for his courage in discussing a subject which presents so many points of view, and secondly for the admirable way he has summarized the problems now confronting the wire-drawing industry.

It is perhaps unfortunate for the wire-drawing machinery manufacturers that the larger wire manufacturers in the U.K. got away very quickly with their own designs following the introduction of the tungsten carbide die, and until recent years they have not really overcome the difficult problem of the design of equipment suitable for large-scale manufacturing conditions. It is to the credit of the designers and builders of wire-drawing machinery in the U.K. that they are now in a position to offer equipment which is becoming attractive to the larger operators. The problem of the production of suitable and reasonably priced machinery has been bedevilled by the support given by smaller manufacturers, mainly abroad, who have required machinery suitable for drawing wire of a wide diversity of size and quality.

This has inevitably forced design along the path of direct current, with separate motors to each block. Together with ancillary rectification and control gear this had had the unfortunate effect of raising the cost of such machines beyond the range of economic price in the mass-production mild-steel wire field and is of some concern to wire manufacturers faced with the necessity of large scale re-equipment.

Reductions per pass for mild steel are at least 40%, whereas for patent steel these rarely exceed 28% and are often lower. If a machine has to be designed to cover this wide range the cost of electrical equipment is certain to climb beyond an economic level.

It seems therefore that there is a tendency to over-develop the wire-drawing machine. For mild steel, the storage machine with its wapping-off from block to block is entirely suitable, provided that the storage can be brought under automatic control so that the operator is relieved of the constant attention required to prevent intermediate blocks building up too far or running off. So far this problem has not yet been solved satisfactorily.

As so much of this wire is required for further processing (e.g. for nails and galvanizing) the production of large-weight pieces is essential, but it is a moot point whether the provision of 4000-lb. pieces on heavy drums is likely to lead to any gain. Experience has shown that coils of 1000 and 2000 lb. weight, depending on gauge of wire, offer most of the advantages required, and the cost of a machine should not be increased to provide for anything heavier.

A great deal of wire will be required in small-weight pieces for ease of handling in the multitude of small manufacturing processes that are fed by the wire industry, and the cost of splitting larger pieces and re-tying can easily absorb any economies of long continuous runs.

Two methods of coil utilization are shown in Fig. *A*, where a 1100-lb. piece on a transportable stripper is shown ready for transfer to a continuous galvanizing line. Alongside is illustrated the labour engaged in cutting up for customer usage.

The inverted static block might serve both purposes for *mild steel* but the difficulties of dressing the spirally cast wire is a serious disadvantage in the case of patent steel. So much of this type of wire is required to be perfectly cast that the waffle-type machine would seem to be doomed for this trade, and straight-line drawing and coiling must take its place.

Mr Richards rightly points out that cooler drawing conditions can be obtained by spreading the total reduction in area over a larger number of blocks, and the greater speeds of some recently designed machines have made this necessary. This has increased the cost of the machine, almost directly proportional to the extra blocks, and more attention must be paid to effective cooling.

The colder patent steel wire is drawn the better are its useful properties, and it is unfortunate that the most satisfactory way of doing this is still the storage principle, with the longer time it permits in contact with the water-cooled block.

Mr. Richards makes a strong plea for higher finishing speeds in the steel-wire industry. Greater speed does not necessarily mean greater efficiency, which can only be measured in terms of the weight of wire that can be produced per man in a given period of time. In large-scale

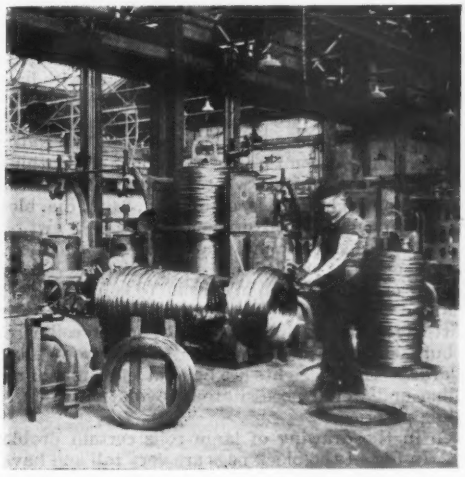


Fig. A—1100-lb. piece on transportable stripper

practice there is no evidence that very high speeds can materially improve efficiency if measured on this basis, and Mr. Richard's statement must be viewed with considerable caution.

Mr. **Richards:** I agree that wire-drawing machines are being overdeveloped, but machine manufacturers are driven to this by the wire users, who cannot make up their minds about the exact operation and product required of their machines.

The large 4000-lb. pieces to which I referred are those to go in front of the machine, not in the back. With 4000 lb. on the front of the machine it is possible to run at the maximum speed the wire will stand. So many machines are being held back from the speed point of view because so much time is spent getting ready for another run. The 4000-lb. piece is the obvious way of overcoming that difficulty.

Continuous coilers are valuable, but only for mild steel; there is not much scope for them with high-carbon steel, because of the difficulty with twist on the high-tensile material.

Higher speeds mean more than just revolutions per minute; they imply, in a sense, increase in the productive efficiency of the machine. There are machines today which run at an efficiency of about 94%, but it is possible to make them run half as fast again, still at 94% efficiency, with a corresponding increase in production.

Mr. **R. Stewartson** (Guest Keen and Nettlefolds (South Wales) Ltd.): My points concern solely the mass production of low- and medium-carbon wire drawn from rod to all gauges down to 20 or 23. Could Mr. Richards elaborate on the trends in continuous wire-drawing machine speeds for such products? My own company, for example, largely equipped with pre-war machinery, is drawing wire at 1500–2000 ft./min. and present practice for mild steel does not show much advance on this, although machines have been available for faster work for some time. Since no one has yet taken up large-scale production at very high speeds, does Mr. Richards think that in the foreseeable future substantial speed increases are likely to be accepted in the ferrous trade? Certainly, high-speed machines not only involve heavy capital investment, particularly in powerful D.C. driving equipment and control gear, but must be tended by operators intelligent, quick-thinking, and above all with rapid reactions. On the other hand, the low-speed machines (particularly the accumulation type with simple A.C. drives) are cheap, and one operator can look after two or three of them. For the latter reason the output per operator does not seem to be very dependent on machine speed. In addition, low die wear, elimination of the cooling problem, and reduction in wire breakage have an important effect on spindle efficiency.

Wire coil weights are largely a function of rod coil weights (generally 400–500 lb.), dictated by the rod-mill billet size. This does not necessarily apply on continuous wire-drawing machinery, where welding is practised. Even so, the weights produced on, say, 24-in. dia. blocks (with certain exceptions) do not exceed 4–5 cwt. and such coils are about the maximum weight for manhandling. Is the weight of a rod coil to remain static? Heavy gauges are currently rolled in coils up to 900 lb. and there is one rod mill in the U.S.A. taking 1400-lb. billets. Admittedly these are divided midway in the rolling process, but 700-lb. coils of 5-gauge rod are heavy by present standards. These weights are beyond the limits of manhandling and would necessitate a revolution in current handling practice.

Even in the drawing of large coils certain problems arise. In Fig. *A* the block pegs are very tall and have to be guarded with steel plates, whilst after removal from the machine the coil is too big to stand by itself and has to be carried on its stripper to the next process. To get a coil of this weight suitable for tying and despatching in the normal manner, a large-diameter block (36–40 in.) might be necessary. The continuous coiler might prove useful for such coil weights, but in its present design form, is it capable of processing wire heavier than about 8 gauge? For it is with heavy gauges that such a device shows advantages over normal methods. A 500-lb. coil of 10-gauge wire drawn at 1000 ft./min. is produced in 11½ min., whereas a similar weight coil of 5-gauge wire takes only 5 min. at 850 ft./min. The saving in stoppage time and increase in spindle efficiency is much greater in the latter case, and I would suggest that the continuous coiler be developed to accept heavy gauges of wire.

Spooling offers an alternative method of producing heavy coils and is widely used in the non-ferrous industry, but the disadvantage is in the spool itself, which if sent to a customer has to be returned. This makes the method unattractive except for internal processing or individual customers taking a steady flow of wire. The actual cost of spools may run into tens of thousands of pounds, whilst the spooler itself is not inexpensive. On the other hand, the spool is a compact form of storing wire and minimizes damage during transit. Indeed, there seems to be no ideal system for producing heavy coils.

The types of wire machine which Mr. Richards has so well described go a long way towards providing adequate cooling, but surely the best place to apply cooling is at the point of heat generation in the wire itself. Does Mr. Richards foresee the wide use of wet drawing in the future as an answer to the problem of high speeds for mild steel?

Mr. **Richards**: I agree that in general speeds higher than 1500–2000 ft./min. cannot be achieved, but there are machines which are reducing wires 60% faster. Speeds will certainly continue to rise, and this is progress in the right direction, from the point of view of international competition.

In regard to the 4000-lb. rod, Mr. Stewartson has given part of the answer. A 1400- or 1500-lb. rod is already in use in the U.S.A. If the rod weighed 5000 lb., it would run longer with less welding and less trouble. The introduction of a heavier rod is bound to be an improvement. I do not know, however, whether it is worthwhile economically to go forward on these lines with the machinery at present in use; the handling equipment is certainly not able to deal with heavier rod.

Mr. **D. Reilly** (Guest Keen and Nettlefolds (South Wales) Ltd.): I do not think that '94% efficiency' in itself means anything at all; it must be related to a diameter and to the speed of the machine. This figure could not, for example, apply to a large bull block. There must be a certain limit on speed. Reference has been made to the saving in manpower, but the manpower is not confined to the wire drawer. What about maintenance engineers and the electricians who are necessary to maintain these high-speed wire machines? The introduction of the tungsten carbide die in itself, combined with low-speed wire-drawing units requiring little or no maintenance, might well bring us to automatic wire-drawing plant of the future.

When we speak of high speeds, we always think in terms of the machine, following U.S. practice. One of the effects of this high speed is to induce a certain amount of industrial neurosis when a man is asked to concentrate so highly on this type of machine.

If a large number of low-speed machines are used, in the event of a breakdown the percentage of production time lost is less than it is on a much smaller number of high-speed machines.

Mr. **Richards**: We have overdone the complication of wire-drawing machinery. Wire manufacturers are always wanting elaborate machines for a simple job. An elaborate machine is generally less efficient than a simple machine for doing any specific job. The extra money spent is never recovered, although the machine is always available to do something it is rarely required for. However, it would be wrong to go to the completely simple machine, drawing through one die at a time. A compromise must be struck. If a user can keep a machine running on 16-gauge wire, his machine should be made for this and nothing else. An A.C. drive is quite adequate for this purpose.

The 94% efficiency quoted was not on a bull block, but on a 5-hole machine drawing mild steel from 5-gauge rod and making about 8 tons per shift. In itself 94% efficiency at 94 ft./min. is unremarkable, but the same efficiency at 1800 ft./min. is very good. Working efficiency must be tied to a reasonable speed.

Dr. **L. N. Bramley** (B.I.S.R.A.) : Two points strike me as one who is interested in automatic control. The first is that the machine is continually being stopped unless an automatic coiler is used, so that the wire may be taken off when enough has been drawn. The automatic coiler allows the wire to be removed without stopping the machine, but it is a very bad feature, since with hard-drawn steel wire it apparently leaves a great deal of twist in the wire. It should be possible to take an ordinary coil, on a drum or some kind of cylindrical device, out of the machine without slowing it down at all, and put in a new one. A good example of this is in paper mills, where newsprint 24 ft. wide. is rolled on to a mandrel of about 6 in. dia. to 2 ft. 6 in. dia. in 20 min. The paper is rolled at 1400 ft./min., and the whole roll is changed without slowing the machine down and without any trouble.

It should be possible to devise an automatic method of changing a small roll of wire without stopping the machine. The only reason why a wire-drawing machine should ever be stopped should be to put in new dies.

The automatic coiler is said to be rather difficult to manipulate in the case of hard-drawn steel wire. A well known principle of coiling wire might be implemented in this connection. Anybody who has rolled up an electric-fire flex knows that if one takes hold of the plug and rolls towards the fire, when the flex is coiled it is twisted. If one rolls from the fire to the plug, however, it untwists and is very easy to coil. What is not generally known is that if one starts from the plug, puts a coil on, and then changes hands, coiling alternately with either hand, there is no twist in the wire at all when fully coiled. An automatic coiling machine could be made on those principles, and I think its design could be a relatively easy matter.

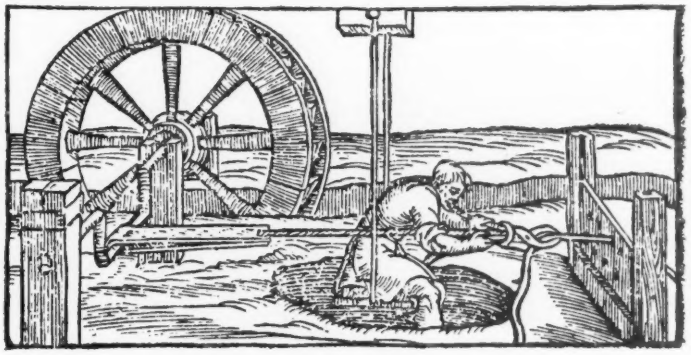
Mr. **Richards**: Dr. Bramley's suggestion has been tried and machines embodying it are on the market for continuous running reels, but I have had no experience of them. I understand that they are not too satisfactory and do not operate at high enough speeds.

The **Chairman** : It is sometimes said that plant manufacturers on the whole tend to overlook the question of accident prevention, and the effect on human individuals of the incessant demand for higher speeds and outputs. I am not personally against higher speeds unless there is a price to be paid for them in higher accident rates or industrial neurosis. I know nothing about either of these two so far as the wire-drawing industry is concerned, but I am also sure of the statements made to the effect that speed necessarily means higher accident rates are completely wrong. Perhaps Mr. Richards could say whether the higher speeds he has been talking about can be obtained without increasing either accidents or neurosis.

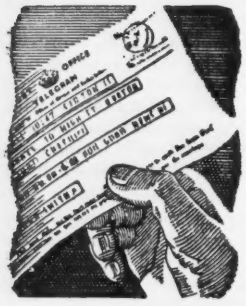
Mr. **Richards**: Higher speeds will increase accidents because operation becomes more difficult and men tend to become afraid of their machines. As manufacturers we have never tried to produce a machine that has gone faster than our competitors'; our aim has always been to provide one that gives a little more efficiency when running.

We are doing more than ever to make our machines reasonably safe from the point of view of the operator. Once it was left to him to find out whether the machine was safe or not, but manufacturers are generally now taking pains to ensure that machines are as safe as they can be made with the means at their disposal.

The **Chairman** : If industrial machines run faster we may well find ourselves surrounded by such a multiplicity of legislation and prescription that we shall not know which way to turn. This is a matter of fundamental importance in all types of machinery.



Drawing heavy wire by means of water power
(reproduced from the *Pirorechnia* of Vannoccio Biringucio)



N E W S

Announcements and News of Science and Industry

IRON AND STEEL INSTITUTE
Special Meeting in Scunthorpe

The Institute's Special Meeting which was held in Scunthorpe from 11th to 14th October, 1955, by invitation of the Lincolnshire Iron and Steel Institute (President, Lt. Comdr. G. W. Wells, R.N. (Retd.)), was attended by about 300 Members and 140 Ladies. The programme was given in the October issue of the *Journal*. Members and Ladies were entertained most hospitably by the Mayor and Corporation, the Lincolnshire Iron and Steel Institute, and the managements of the local works.

The Ladies' Committee (Chairman, Mrs. G. W. Wells), went to great trouble to provide a programme of exceptional interest for the ladies. The Dinner and Dance at Elsham Hall were particularly successful.

An account of the meeting and report on the discussions at the technical sessions will be published later.

Presentation of the Sir Robert Hadfield Medal for 1955

During the opening session of the Special Meeting in Scunthorpe, The Hon. R. G. Lyttelton, Past-President, presented the Sir Robert Hadfield Medal for 1955 to Mr. Tor Fjalar Holmberg of Oy Vuoksenniska AB, " in appreciation of his meritorious service in improving the technique of the production of iron and steel " at the Imatra Works, Finland.

Relations with Foreign Societies
Société Française de Métallurgie—Report on Meeting

The " Journées Métallurgiques d'Automne " of the Société Française de Métallurgie were held in Paris from 24th to 29th October, 1955. The meeting was well attended and was a great success. As usual, a large number of papers covering a wide range of interests, ferrous and non-ferrous, were presented at the technical sessions, held usually two at the same time, in the Maison de la Chemie. Abstracts will be printed in the *Journal* when the papers are published in *Revue de Métallurgie*.

At the opening meeting the President, Monsieur Raoul de Vitry, welcomed the numerous visitors from other countries and gave a review of the work of the Society. Later he presented the Society's Osmond Medal to Monsieur Pierre Chevenard, who delivered a lecture on the efforts to continue the work of Osmond on the thermal analysis of materials and experiments in metallography. Social functions included a luncheon for foreign visitors and a banquet, to which ladies were also invited, at the Union Interalliée. The proceedings included a visit to the Mint on Friday afternoon.

Verein Deutscher Eisenhüttenleute—General Meeting, Düsseldorf

The " Eisenhüttentag " of the Verein deutscher Eisenhüttenleute was held in Düsseldorf on Thursday and Friday, 3rd and 4th November, 1955. On the evening before the meeting opened, a party for visitors from overseas was given by the Lord Mayor of Düsseldorf, Mr. Josef Gockeln, in the Rococo Palace of Benrath.

The Membership of the Verein, which was founded 95 years ago, now exceeds 7700. Over 4100 Members registered for the meeting. Several simultaneous technical sessions were held on 3rd November, and the attendance at each of these varied from 300 to over 1300. The General Meeting on the following day was held in the Apollo-Theatre. This was filled to capacity (about 2500) and the proceedings were reported by loud speakers to an overflow meeting. Most of those who had registered took part in the informal " Kameradschaftsabend " in the Rheinhalle on Wednesday evening, and about half this number in the more formal luncheon which followed the General Meeting and with which the proceedings concluded.

Professor Dr.-Ing. Herman Schenck, President, was in the Chair.

The technical papers were selected with a view to being of interest to a large proportion of the participants. Abstracts will be printed in the *Journal* when they are published in *Stahl und Eisen*. The general Meeting included reviews by Dr. K. Thomas, Director, of the work of the Verein, and by Prof. Dr. H. Schenck, President, on Progress of the German Steel Industry, as well as a Report by Dipl.-Ing. A. Tix, General Works Manager of the Bochumer Verein A.G., on " *Practical Aspects of the De-Gassing of Steel in Vacuo, with Particular Reference to Large Ingots for Forging.*" There was also a lecture by Professor Dr. Romano Guardini of Munich on " *Man, an Uncompleted Being, and Might.*"

The proceedings lasted from 9.15 A.M. to 1.45 P.M.

Among the visitors were representatives of the Governments of the German Federal Republic and of the Land Rhein-Westfalen, Monsieur René Mayer, President of the High Authority, Luxembourg, and representatives of industrial, scientific and technical organizations in Germany and many other countries.

Honorary Membership of the Secretary

During the proceedings at the General Meeting on 4th November, the President, Professor Dr.-Ing. H. Schenck, announced that it had been unanimously decided to nominate Mr. Kenneth Headlam-Morley, Secretary of The Iron and Steel Institute, to be an Honorary Member of the Verein. The citation bore tribute to his work in encouraging over a long period of time the exchange of ideas among those engaged in the iron and steel industries and in fostering in a spirit of true friendship the activities of the Verein to the mutual benefit of the British and German Institutes.

Mr. Headlam-Morley, in expressing his appreciation, welcomed the successful collaboration which had been established over so many years between the Verein and the Institute.

There have been 28 Honorary Members since the Verein was reconstituted in 1880. These include, as the only British recipients of this honour, Sir Hugh Bell, Bt. (1910) and Mr. James Henderson (1937).

NEWS OF MEMBERS

▶ Dr.Ing. E. F. O. Alton has left the Cox Engineering Company Ltd., and has joined Heinrich Fischer, A.G., in Germany.

▶ Mr. L. Badone has left Light Alloys Ltd., Ontario, and has taken up the position of metallurgist "A" with the Engineering Division of Avro Aircraft Ltd., Malton, Ontario, Canada.

▶ Mr. W. D. Biggs has obtained the degree of Ph.D. from Birmingham University and has returned to Murex Welding Processes Ltd.

▶ Mr. A. C. Brearley has joined the Board of Catton and Co., Ltd., Leeds, as Technical Director.

▶ Mr. D. R. Brown of Ashmore, Benson, Pease and Company, has been appointed Divisional Manager of the Blast Furnace Division of the Power-Gas Corporation Ltd. group of companies.

▶ Mr. R. Burrows has been appointed Manager of the Western Branch of Dewhurst and Partner Ltd., Gloucester.

▶ Dr. P. W. Clark has left the Derbyshire Silica Firebrick Co., Ltd., to become Chief Technologist of J. & J. Dyson Ltd., Stannington, Nr. Sheffield, and a Director of Yorkshire Testing Works, Ltd., and Beecroft & Partners (Metallurgists) Ltd.

▶ Mr. T. P. Conway has gained the degree of B.Sc.(Eng.) of London University, with 2nd Class Honours. He has also been awarded a Clayton Fellowship of the Institution of Mechanical Engineers, for postgraduate study and research in the School of Applied Mechanics at Sheffield University.

▶ Dr. A. Edwards has been elected a Fellow of the Institute of Physics.

▶ Dr. A. E. El-Mehairy has recently taken up an appointment as Lecturer in Metallurgy at the Faculty of Engineering, Cairo University.

▶ Mr. D. Griffiths has now joined the staff of Richard Thomas and Baldwins Ltd., Ebbw Vale.

▶ Mr. W. S. Langford has retired from Messrs. F. Issels and Son Ltd., Southern Rhodesia, to take up residence at the coast in Durban, Natal.

▶ Mr. Peter Latham and Mr. E. G. Spooner have been appointed to the Board of the Whitehead Iron and Steel Co.

▶ Mr. G. Shaw Scott, Secretary-Emeritus of the Institute of Metals, has been elected a Fellow of that Institute.

▶ Mr. W. M. Service has resigned from Mechans Limited, and has now taken up the position of Sales Representative with R. B. Tennent Ltd., Coatbridge.

▶ Mr. M. D. Smith has taken up the position of a Technical Officer with the Metals Division of I.C.I. Ltd.

▶ Mr. L. H. Toft has left the Mond Nickel Company to take up the position of metallurgist at the Central Electricity Authority's Research Laboratories in Leatherhead, Surrey.

▶ Mr. A. Torry has been appointed a Director of the Sheffield Forge and Rolling Mills.

▶ Mr. J. P. Warner has left the University of British Columbia to take up the position of Economist with Sherritt-Gordon Mines Ltd., Chemical Metallurgical Division, Alberta, Canada.

▶ Mr. M. J. Weldon has left Henry G. Thompson and Son Company, to take up an appointment as metallurgist with the North Eastern Steel Corporation, Bridgeport, Conn., U.S.A.

▶ Mr. J. B. Wilson has left Magnesium Elektron Ltd., to take up the post of Chief Engineer at English Racing Automobiles Ltd., Dunstable.

▶ Mr. K. J. B. Wolfe has resigned from B.S.A. Tools Ltd., to take up a position with the Triplex Safety Glass Co.

▶ Mr. R. Woodward has obtained the degree of B.Sc. in Metallurgy from the University of Durham. He is now working in the Metallurgical Laboratory of the Fairey Aviation Company, Hayes, Middlesex.

▶ Professor Howard K. Worner has accepted an invitation from the Broken Hill Pty. Co., Ltd., to become Director of Research in their new division near Newcastle, Australia. He will be taking up this appointment in January next.

Obituary

▶ Mr. Edward Baker of the Kilnhurst Steel Works, Sheffield, on 16th September, 1955.

▶ Colonel N. T. Belaiew, C.B., Bessemer Medallist in 1937, on 5th November, 1955.

▶ Mr. Ernest Gerald King, Chairman of The Louis Cassier Co., Ltd., at the age of 78.

▶ Mr. R. B. Lane, Steel Plant Manager of the Rhodesian Iron and Steel Commission's works at Que Que, on 18th September, 1955.

▶ Mr. H. R. Pearce of Altrincham, Cheshire, on 15th September, 1955.

▶ Colonel H. B. Sankey of Messrs. Joseph Sankey and Sons Ltd.

▶ Dr. H. L. Saunders, formerly head of the Ironmaking Division of B.I.S.R.A., on 14th October, 1955.

▶ Mr. H. W. Williams of Church Stretton, Shropshire.

IRON AND STEEL ENGINEERS GROUP

The **Twenty-Ninth Meeting** of the Iron and Steel Engineers Group will be held at the offices of the Institute at 4 Grosvenor Gardens, London, S.W.1, on **Wednesday, 14th December, 1955.** The Morning Session from 10.30 A.M. to 12.45 P.M. will be devoted to the presentation and discussion of a paper on "*The Roller Straightening of Sections and Rails*," by W. A. J. Dinwoodie. Buffet Luncheon will be served in the Library from 12.45 to 2.0 P.M.

During the afternoon Session, from 2.0 to 4.0 P.M., a paper on "*Flying Shears for Bars and Billets*," by R. Stewartson and S. R. Phelps, will be presented and discussed. The papers were published in the November issue of the *Journal* (pp. 232–272).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Dr. H. L. Saunders

As recorded in the News of Members column, Dr. Saunders, who was the first head of the Ironmaking Division of the Association, died on Friday, 14th October.

Dr. Saunders was a graduate of the University of Wales. His research in physical chemistry was followed by a Fellowship at the University of Liverpool and the degree of Ph.D. in 1924. During this period he worked on thermal decomposition, vapour pressure, salt pair systems, and photosynthesis. He came to Imperial College, London, in 1925, to work on the mechanism of blast-furnace reactions. This work was financed by the National Federation of Iron and Steel Manufacturers (now the British Iron and Steel Federation), later by the Iron and Steel Industrial Research Council. Dr. Saunders was therefore one of BISRA's earliest links with the steel industry's organization for co-operative research, which preceded the foundation of the Association.

Although Dr. Saunders occasionally extended his activities to the fields of spectroscopy and gaseous combustion, his main interest centred upon the smelting of iron. He was appointed special lecturer in thermometallurgy at Imperial College in 1939, and built up a research team to work in the blast-furnace laboratory. In 1945, his work was transferred to the Association,

where he became Head of the Ironmaking Division from which position he had to retire owing to ill health. An admired and respected colleague, he leaves a widow and a daughter.

NEWS OF SCIENCE AND INDUSTRY

Radioactive Isotopes

The Chemistry Dept. of Battersea Polytechnic has arranged a course of Lectures on "*An Introduction to Some Uses of Radioactive Isotopes.*" The course, of about 10 lectures, is designed for non-specialists, such as practising engineers and metallurgists, and is to be a general introduction to the uses of radioactive isotopes in industry.

The Lectures will be held at the Polytechnic, Battersea Park Road, London, S.W.11, on Tuesdays, from 7.0 P.M. to 9.0 P.M., and will commence on 10th January, 1956. The fee for the course is £1 0*s.* 0*d.*, and further details can be obtained from the Secretary (R.A.I. Course) at Battersea Polytechnic.

Mond Nickel Fellowships 1955

The Mond Nickel Fellowships Committee announces the following awards for 1955:

D. H. BUTLER (The Phosphor Bronze Co., Ltd.): To study the production of copper and its alloys, with particular attention to foundry methods, in the United Kingdom, on the continent of Europe, and in America.

R. W. N. DRON (Rhoanglo Mine Services Ltd.): To study the organization of research and its relation to production in extraction metallurgy in the United Kingdom and North America.

W. F. DUNCAN (The British Aluminium Co., Ltd.): To study the design, layout and operation of continuous strip mills, considering in particular metal behaviour, properties and quality, roll lubrication and cooling, and the development of automatic controls.

R. H. HANNAFORD (The British Iron and Steel Research Association): To study organization and practice in the ferrous foundry industry in the United Kingdom, Europe and the United States, with particular reference to layout, mechanization, and the application of management techniques.

R. J. HARBORD (John Lysaght's Scunthorpe Works Ltd.): To study the development of continuous casting in the non-ferrous industry and its application to the production of steel.

Board Changes—Richard Thomas and Baldwins, and Steel Company of Wales

The Boards of these two Companies have been reconstructed as follows:

Richard Thomas and Baldwins—Sir Ernest Lever (*Chairman*), Mr. G. H. Latham (*Deputy Chairman*), Mr. H. F. Spencer (*Managing Director*), Mr. G. A. Young (*Asst. Managing Director*), Sir Wilfrid Eady, Mr. E. O. Faulkner, Mr. R. T. Pemberton, and Mr. C. A. U. Rhys.

Steel Company of Wales—Mr. H. Peake (*Chairman*), Sir Charles Bruce-Gardner (*Deputy Chairman*), Mr. E. J. Pode (*Managing Director*), Capt. H. Leighton-Davies and Mr. W. F. Cartwright (*Asst. Managing Directors*), Sir Robert Barlow, the Earl of Dudley, Mr. S. E. Graeff, and Col. A. T. Maxwell.

DIARY

1st Dec.—LEEDS METALLURGICAL SOCIETY—"*Radiation Damage in Metals,*" by W. M. Lomer—Large Chemistry Lecture Theatre, University of Leeds, 7.15 P.M.

2nd Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—Dinner Dance—The Royal Victoria Hotel, 7.0 P.M.

5th Dec.—THE INSTITUTE OF BRITISH FOUNDRYMEN—"*Mechanized Foundries and their Control,*" by H. A. Fox—Sheffield College of Commerce and Technology, Dept. of Engineering, Pond Street, Sheffield, 1, 7.15 P.M.

6th Dec.—EAST MIDLANDS METALLURGICAL SOCIETY—"*Surface Effects in Fatigue,*" by B. Hall—Technical College, Nottingham, 7.30 P.M.

6th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Production Control Quantometer for Steelworks Analysis,*" by D. Manterfield and W. Sykes (Joint meeting with The Iron and Steel Institute, The Royal Institute of Chemistry, and The Society of Engineers and Metallurgists)—The Engineering Theatre, Sheffield University, St. George's Square, 7.0 P.M.

7th Dec.—THE INSTITUTE OF FUEL (YORKSHIRE SECTION)—"*The Two-stage Gas Producer,*" by P. Clarke—Royal Victoria Hotel, Sheffield, 2.30 P.M.

7th Dec.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY—"*Industrial Uses of Atomic Energy,*" by K. J. Bobin—Whitehead Institute, Cardiff Road, Newport, 7.0 P.M.

7th Dec.—MANCHESTER METALLURGICAL SOCIETY—"*Forging Research at B.I.S.R.A.,*" by P. M. Cook—Lecture Room, Central Library, Manchester, 6.30 P.M.

8th Dec.—NORTH EAST METALLURGICAL SOCIETY—"*Commercial Zinc Coatings and their Performance,*" by R. W. Bailey—Cleveland Scientific and Technical Institution, 7.15 P.M.

8th Dec.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—"*Oil and Gas Firing of Open Hearth Furnaces,*" by K. F. Bray—Station Hotel, Dudley, 7.30 P.M.

10th Dec.—INSTITUTE OF BRITISH FOUNDRYMEN—"*Water Cooled Cupola,*" by W. Y. Buchanan—Royal Technical College, George Street, Glasgow, C.1, 3.0 P.M.

10th Dec.—THE SWANSEA AND DISTRICT METALLURGICAL COMPANY—Discussion on Open Hearth Flames, by Professor M. W. Thring—Central Library, Swansea, 6.30 P.M.

12th Dec.—"*Effects of Surface Treatment on the Friction and Wear of Mild Steel,*" by J. W. Midgley—Chemical Engineering Dept., Imperial College, London, S.W.7, 3.0 P.M.

12th Dec.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—Annual General Meeting. "*Applications of Hard Metal Tools.*"

13th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—Film Night—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield, 3, 7.0 P.M.

14th Dec.—IRON AND STEEL ENGINEERS GROUP—Twenty-Ninth Meeting—Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1, 10.30 A.M.

15th Dec.—INSTITUTION OF ELECTRICAL ENGINEERS—"*Intensification of the X-Ray Image in Industrial Radiology,*" by W. F. Cox and A. Wemet—Savoy Place, London, W.C.2, 5.30 P.M.

16th Dec.—IRON AND STEEL INSTITUTE, WEST OF SCOTLAND—"*Some Aspects of Blast Furnace Operation,*" by E. H. Baldwin—39, Elmbank Crescent, Glasgow, C.2, 6.45 P.M.

21st Dec.—NORTH WALES METALLURGICAL SOCIETY—Discussion Night—County Primary School, Plymouth Street, Shotton, Nr. Chester, 7.15 P.M.

5th Jan.—LEEDS METALLURGICAL SOCIETY—"*The Production of Pure Metals,*" by J. W. Chaston—Large Chemistry Lecture Theatre, University of Leeds, 7.15 P.M.

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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FUEL—PREPARATION, PROPERTIES, AND USES

Pin-Fin Heat-Exchanger Surfaces. W. M. Kays. (*Trans. Amer. Soc. Mech. Eng.*, 1955, **77**, May, 471–483). The author summarizes the previously available heat-transfer and flow-friction design data for pin-fin heat-exchanger surfaces and presents further data recently obtained.—D. H.

Differential Thermal Analysis of Coking Coals. H. D. Glass. (*Fuel*, 1955, **34**, July, 253–268). The results of a study of coking coals using this technique are reported. The analysis enables a preliminary evaluation of the coking ability of coals to be made.—B. G. B.

On the Problem of Utilizing Low Grade Coals for Coking in the Steel Industry. J. Rešetňak. (*Paliva*, 1955, **35**, (4), 104–109). [In Czech]. On the basis of theoretical considerations and laboratory experiments it is shown that some low-grade coals are suitable for coking provided they are first freed from dust.—P. F.

The Occurrence of Sulphur in British Coals. A. M. Wandless. (*J. Inst. Fuel*, 1955, **28**, Feb., 54–62). The forms of sulphur in coals are discussed and the distribution and trends of the sulphur content of British coals are described by reference to many analyses from all the coalfields. While the production of high-sulphur coals will continue to rise for some time, the deterioration will not be so bad as in the last 16 years.

Methods and Objects of De-Watering Fine- and Finest-Grain in the Beneficiation of Coal. K. Lemke. (*Glückauf*, 1955, **91**, Apr. 23, 452–65).

The Aptitude of Fine Coals for Flotation. P. Moiset. (*Publ. Assoc. Ing. Faculté Polytechn. Mons*, 1955, (1), 1–15). Factors affecting flotation yield were examined, in particular particle size and inorganic ash content. Flotation of various mixtures of coals of different particle size and with different ash contents was also investigated, and surface active agents were studied.

Production of Coked Briquettes from Western Australian Sub-Bituminous Coals. R. Broadbent, R. P. Donnelly, and N. Platell. (*J. Inst. Fuel*, 1955, **28**, Jan., 3–16). Details are given of an investigation into the production of briquettes from Australian Collie non-coking coal for use as cupola fuel. Good results were achieved on laboratory scale by making tar- or pitch-bonded briquettes of the charred coal, and giving a low-temperature carbonization. An attempt is made to assess their practical value.—D. L. C. P.

Preparing Blast-Furnace Flue-Dust for Blast-Furnace Charging by Pelletizing. K. Janeczek. (*Hutnické Listy*, 1955, **10**, (1), 24–29). [In Czech]. By rotation in a drum-type mixer at 70° C., with 20% water additions, the dust and ore mixture agglomerates into balls of up to 2 in. dia. They can be charged after pelletizing in a rotary furnace, but could be used green if careful handling is possible, i.e. where belt charging is installed.—P. F.

The Storage of Coal. D. A. Hall. (*Steam Eng.*, 1954, **24**, Oct., 3–5, 16; Nov., 56–58; Dec., 96–100; 1955, Jan., 142–144; Feb., 177–179; Mar., 199–200, 223). Data are presented on losses due to storage and to spontaneous combustion. Conditions for safe storage are given. The building of well-compacted heaps, and the exclusion of air by various means are among the preventive measures dealt with.—T. E. D.

The Jamshedpur Coking Plant. (*Coke Gas*, 1955, **17**, Apr., 127–132; May, 167–172). The modernization and expansion of the Jamshedpur works of the Tata Iron and Steel Company in India are described, with particular reference to the coke ovens. The programme began in 1935, and the 4 batteries of 40 ovens each, with a total capacity of 2400 tons/day, have been replaced by one battery of 54 ovens, two of 55 ovens each, and one of two blocks of 26 ovens. Capacity is now 5200 tons/day, and 26 more ovens may be added to No. 4 battery. The ovens were built by Simon-Carves. No. 4 battery, installed 1950–53, and its ancillary equipment, are described. By-product plant is mentioned. Proposed modernization of No. 1 battery, by-product plant, ore-bins, soaking pits, and steel melting shop is surveyed. A plan of the coking plant is given.—T. E. D.

Pumping of Liquids on Gas Works. L. J. Clark. (*Inst. Gas Eng. Comm.*, 1955, May, 466). A detailed examination is made of the selection, design, and operation of pumps for use on gas works (including coke-oven plants).—B. G. B.

New Knowledge in the Appraisal and Production of Coke with Respect to Its Use. W. Reerink. (*Stahl u. Eisen*, 1955, **75**, Mar. 24, 322–335). The author reviews the methods used in the appraisal of metallurgical coke and suggests a new index which characterizes the coke properties better than those introduced previously. He also developed a method for the determination of the reactivity of coke based on the specific reaction rate (velocity constant) and the activation energy.—T. G.

Several Tests on Sarro-Lorraine Mixtures. Mehl. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (3), 557–562). Tests relating quality of the coke obtained to constituents used in the mixtures are reported.—T. E. D.

Industrial Trial with Coke from the Base of the Sarrois Coals and with Semi-coke. A. Bouillot and others. (*Rev. Mét.*, 1955, **52**, Jan., 63–79). Sarrois and Lorraine coals have up

to now generally been considered unsuitable for making metallurgical coke, without the addition of coals from other basins. The administration of the Mines de la Sarre, the Marienau experimental station, and the Forge de Dilling recently organized a trial in a blast-furnace using coke only containing 13% semi-coke and Sarrois coals. The results of the trial are given in this paper.—G. E. D.

Recent Laboratory Tests to Determine the Suitability of Coals for Coking. A. F. Boyer and J. Lahouste. (*Rev. Ind. Min.*, 1954, **35**, Nov., 1107–1133). It has not hitherto been possible to predict how coke from a given coal will fissure, but several practical methods are suggested in which the contraction of coke is related to temperature. These methods include the direct measurement of this contraction at about 500° C., indirect estimation from the temperature of re-solidification, and the measurement of the curvature of a small disc of coal for a given thermal gradient. Techniques are described and results discussed.—G. E. D.

The Production of Iron Coke from Highly Bituminous Coal. H. Barking and C. Eymann. (*Stahl u. Eisen*, 1955, **75**, Apr. 7, 386–391). Gas coal (i.e. highly bituminous coal) is not suitable for the production of high-grade metallurgical coke; but a metallurgical coke can be produced from a mixture of bituminous coal and iron ore up to 43%. The incorporation of iron ore into the coke has many metallurgical advantages. The drum strength of iron coke containing 12–35% iron is equal to that of metallurgical coke. The authors describe the production process and the properties of iron coke containing various amounts of iron ore. Experience in the use of iron coke in blast-furnace practice is reported.—T. G.

Increasing Charge Density by Vibrations. R. Loison. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (3), 553–555). An experimental apparatus consisting of a number of vibrating vertical needles, which can be introduced into the charge immediately after it is put in the coke oven, is very briefly described.—T. E. D.

Pilot-Plant Coke Oven Gives Researchers New Tool of Advanced Design. J. Mitchell. (*Iron Age*, 1954, **174**, Dec. 2, 124–125). The oven, belonging to Eastern Gas and Fuel Associates, Mass., has a capacity of 500 lb.; the construction, instrumentation, and operation are described. It is intended for studying the effects of variation in charge composition and of operating variables on the quality of coke; results can be correlated reliably with practice in specific full-scale ovens.—D. L. C. P.

The Evaluation of Coking Coal with the Dilatometer. H. Porsch and O. Dietrich. (*Glückauf*, 1955, **91**, May, 7, 520–523). The use of the dilatometer is described for the study of the degasification of coal in the region of the plastic zone. The possibility is discussed of applying a single "coking coefficient" derived from the dilatometer measurements to evaluate the coal. An illustrative example is given.—L. D. H.

Pressure Conditions in Coke-Oven Batteries. B. Kalinowski. (*Hutnik*, 1955, **22**, (3), 90–98). [In Polish]. The distribution of pressure in the heating system and in ovens and their influence on the operation of a coke-oven battery are discussed. Methods of determining the penetration of flue gases into ovens and raw gas into flues are outlined.—V. G.

Structure of Coke. I—Structure and Properties of Blast-Furnace Coke. K. Inouye and H. Tani. (*Fuel*, 1955, **34**, July, 356–362). An analysis of the variation in physical properties of a blast-furnace coke from wall to centre of the coke oven has been made.—B. G. B.

Coke Quality and Blast Furnace Operating Practice. W. T. Rogers. (*Blast Furn. Steel Plant*, 1955, **43**, June, 627–634). The application of statistical analysis to the study of the relation between blast-furnace performance and coke quality is discussed in detail. Monthly average data from 5 blast furnaces operating during 1950–1953 have been used for the statistical examination. Only a minor part of the blast-furnace performance is attributed to coke quality which is due to very constant level of coke quality being achieved over the test period.—B. G. B.

PRODUCTION OF STEEL

Desiliconization of Blast Furnace Hot Metal. J. Pearce. (*Trans. Indian Inst. Met.*, 1953, **7**, 251–258). Desiliconization by scale additions in the blast-furnace runners and hot-metal ladles, operation of active mixers with or without oxygen lancing, and oxygen lancing in covered ladles are compared.

Decarburizing Reaction with Gaseous Oxygen. A. Carli. (*Met. Ital.*, 1955, **47**, Apr., 161–167). [In Italian]. The exceptionally good quantities of low-carbon steels, obtained from some experimental heats by refining the iron with downwards-blown oxygen without the formation of an active slag, seems to indicate that decarburization happens directly and not by the formation of ferrous oxide diffused in the metal. Small-scale tests seem to confirm this possibility.—M. D. J. B.

French Patent Solves Fume Problem in Oxygen Steelmaking. P. J. Leroy and L. Septier. (*J. Met.*, 1954, **6**, Nov., Section 1, 1189–1191). Details are given of a French pilot plant working on a semi-industrial scale to recover the fume caused by oxygen lancing. Cleaning is carried out in three consecutive stages: first, a scrubbing tower containing a spray nozzle; second, a Venturi tube with a continuous water mist at the constriction; and third, a cyclone collector with water sprinkler. The operating procedure is outlined and the characteristics of the dust are described. Results indicate a 99% efficiency.—G. F.

Gas Metallurgy and the Gazal Process. E. Spire. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Mar., 111–120). Gas metallurgy is defined as the science of using gases in the manufacture of metals. The Gazal process is a technique for the injection of gas into liquid metal via a porous refractory plug. In this way distribution of gas through the metal in the form of very small bubbles can be obtained. A number of applications of the technique for use with molten iron are described, and these include the removal of hydrogen and nitrogen by argon blowing, desiliconizing with oxygen, and desulphurizing using argon blowing to mix slag and metal.—B. G. B.

Note on the Specific Consumption of (Arc Furnace) Electrodes. Royer. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (4), 779–781). Consumption of electrodes of diameters ranging between 200 and 450 mm. is studied and plotted as a function of consumption of electricity.—T. E. D.

Study of the Refining of Water-Jacket Cast Iron Containing Nickel (32%). Trials in a 1500 kg. Furnace. Lefebvre. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (4), 775–778).

Open-Hearth Furnace and Arc Furnace. J. E. Lafon. (*Mét. Constr. Mécan.*, 1954, **86**, Feb., 119–125). The operation of O.H. and arc steelmaking furnaces is compared. The advantages and limitations of each type are discussed and details of the cost distribution for O.H. and arc furnaces manufacturing 300,000 tonnes of carbon steel per year are given. U.S. experience in changing from O.H. to arc furnaces for steel manufacture is described.—B. G. B.

Maintenance of Electric Furnace Bottoms As Practised in Bethlehem Plant. H. C. Bigge. (*J. Met.*, 1955, **7**, Mar., 453–456). Details of the maintenance practice adopted for electric-furnace bottoms at Bethlehem Steel Co. are given. A 96% MgO rammed bottom is installed by the coke process, with drilled holes in the shell as vents. The bottom is washed periodically, resulting in less contamination and cleaner steel.

Preparation and Arc Melting of High Purity Iron. G. W. P. Rengstorff and H. B. Goodwin. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**; *J. Met.*, 1955, **7**, Mar., 467–471). The authors describe a method of purifying iron in batches of 150 lb. or more. Treatment in wet and dry hydrogen is used to remove oxygen, carbon, nitrogen, and sulphur from electrolytic iron flakes, which are then melted into ingots in a special consumable-electrode arc furnace which also removes hydrogen. Typical analyses are given and compared with those of other high-purity irons.—G. F.

Hydro-Arc Control Reduces Costs in Electric Furnace Operation. J. Seymour. (*J. Met.*, 1955, **7**, Jan., Section 1, 17–18). The new hydro-arc control at Kensington Steel Co. uses an air-counterbalanced hydraulic differential, with one constant-speed motor and one variable-speed motor operating in one direction only. Details of the system are given and a comparison is made with the original equipment with hydraulic electrode positioning and reversing motors.—G. F.

An Automatic "Furnace Inspector" for the Protection of Automatically Controlled Industrial Electric Furnaces. G. Sachs. (*Draht, German ed.*, 1955, **6**, Apr., 140–141). The Limitherm electric furnace control unit is described.—J. G. W.

The Electro-Metallurgical Industry of France. M. Moyal. (*Mine Quarry Eng.*, 1955, **21**, Feb., 71–74). One section of this article is devoted to a description of the French production of high-quality steels in electric furnaces. The cold-melt process is most frequently used. There are some 80 arc furnaces and 40 induction furnaces producing special steels.

Some production figures are given and leading producers named.—D. L. C. P.

Stainless Specialty Shop Highlights Trend. (*Steel*, 1955, **136**, Jan. 24, 76, 78). Development at Rotary Electric Steel Co. to extend the production of stainless-steel bars to a large variety of finished bar products is described.—D. L. C. P.

Oxygen Evolution in the Basic Electric Arc Furnace. S. Piérard and P. Flamant. (*Rev. Mét.*, 1955, **52**, Jan., 5–27). Deoxidation of the bath with ferromanganese and of the slag with coke does not result in very low oxygen contents. Lime silicates can also be reduced and returned with silicon to the bath. The use of aluminium as a deoxidant has been studied and very low oxygen contents obtained. Steels so treated have remarkable mechanical properties especially where their resilience is concerned.—G. E. D.

Progress in European Vacuum Melting Described. H. H. Scholefield. (*J. Met.*, 1955, **7**, Jan., Section 1, 25–27). The author briefly reviews recent developments and progress in vacuum melting on a commercial scale in Europe. Particular attention is given to advances in pumping equipment, and the typical layout of a modern high-vacuum high-frequency melting furnace is described.—G. F.

"Tailor Made" Steels. A. M. Hall. (*Battelle Tech. Rev.*, 1955, **4**, June, 69–73). The production and development of steels for use in unusual and special conditions is discussed.

Scales of Acidity and Basicity of Constituents of Slag. S. Yanagisawa, Y. Watanabe, and M. Seki. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, 478–482). [In Japanese]. On the basis of electronic concepts, acidity and basicity scales for oxide constituents of slags have been drawn up, by using thermodynamic cycles. Limitations on their use are explained.

Works Tests regarding the Running and Use of Slags in the Production of Basic Steel and Pig Iron. P. Hüttemann. (*Tech. Mitt.*, 1955, Mar., 133–195). Tests are described which show the influence of various factors on the reduction of manganese and on desulphurization. The constants $K_{Si,S}$ and $K_{Mn.Si}$ are derived. The degree of desulphurization is shown to depend on the kinetics of the reaction and not on the chemical equilibrium position. The use of slag is dealt with.—R. P.

Activities in the Iron-Oxide–Silica–Lime System. J. F. Elliott. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**; *J. Met.*, 1955, **7**, Mar., 485–488). The author correlates data from the literature on various parts of the iron-oxide–silica–lime system and computes the surfaces of α_{FeO}, log γ_{SiO_2}, and log γ_{CaO} at 1600° C. for the liquid ternary system, selecting the pure liquid as the standard state for each component. The results are semi-quantitative and are summarized in diagrams.—G. F.

Effect of Temperature and Atmospheric Evacuation in a Mould on the Fluidity of Steel. Yu. A. Nekhendzi and P. V. Sorokin. (*Liteinoe Proizvodstvo*, 1954, (8), 17–20). [In Russian]. The main part of the work described dealt with effect of mould temperature on the fluidity of steel. Some experiments were also carried out with the mould connected to a reservoir evacuated to a pressure of 300 mm. Hg.—S. K.

New Mould Cooling Pit. K. Nagami and M. Tsubone. (*Sumitomo Metals*, 1954, **6**, Oct., 256–261). [In Japanese]. Improvements in cooling-pit design have increased the life of small ingot moulds; they include a perforated bed which promotes air convection inside and outside the moulds.

Ingot Heat Conservation. The Cooling of Rimming-Steel Ingots Between Teeming and Stripping. M. D. Ashton, R. F. Perkins, and L. H. W. Savage. (*J. Iron Steel Inst.*, 1955, **181**, Dec., 303–312). [This issue].

Commercial Production of Vacuum-Melted Alloys. (*Machinery*, 1955, **87**, July 1, 19–20). The article describes a melting plant of 440 lb. capacity (steel) manufactured by G.A.B., Balzers, Liechtenstein, for the commercial production of special steels and alloys.—M. A. K.

Vacuum Processing of Steel. (*Aciers Fins Spéc. Franç.*, 1955, Mar., 21–22). The use of the vacuum technique during the production of steel as a means of deoxidation, and also of decarburization, is discussed briefly, and reference is made to the advantages of this technique in the production of stainless steels.—E. A. C.

Vacuum Cast 150 Ton Forging Ingots in German Plant. (*Iron Age*, 1955, **175**, Feb. 17, 91–94). A description is given of the techniques used at Bochumer Verein AG for vacuum-degassing large batches of high-alloy casting steels. During the past 2 years more than 10,000 tons have been vacuum-cast for applications such as inductor shafts and turbine rotors for power plants. Large tanks are used which can take a ladle or mould, be sealed, and evacuated to 0·2 mm. by special pumps. Three methods are described: (1) degassing in the ladle; (2) degassing by percolation into a ladle in vacuum; (3) casting of ingots, weighing up to 150 tons, *in vacuo*. The lengthy operations of previous methods are avoided and working conditions improved; better metallurgical quality and reduced manufacturing costs have resulted.—D. L. C. P.

A Statistical Investigation into Factors Affecting the Life of Ladle Linings. J. E. Andrew. (*Trans. Brit. Ceram. Soc.*, 1954, **53**, Oct., 609–620). A statistical analysis of measurements made on teeming ladles in a basic O.H. shop is presented. The ladle lining life was used as a measure of wear, and correlation sought with the variables measured. The following were found of influence: ladle shape, source of bricks, carbon content of steel, time from tap to teem, slag depth. Possible applications of the results to improving practice are considered.—D. L. C. P.

Physico-Chemical Origin and the Effects of the Oxygen Content of Steel. A. Roos. (*Chim. et Ind.*, 1955, **73**, Jan., 61–68). The origin of the oxygen present in steel is explained and its influence on the properties of the metal reviewed. The iron–oxygen system is first examined and then factors influencing the decarburization of liquid steel in the O.H. furnace are discussed. Oxygen in steel is in the form of oxides of the alloying elements and the detection and effect of these oxides is described.—B. G. B.

Continuous Casting of Steel. (*Metal Bull.*, 1955, July 5, 12–13, 16–17). The advantages and problems of this method of casting are discussed. A description of the plant at Welland, Ontario, is given. A list of continuous-casting plants in operation is presented.—B. G. B.

The First French Industrial Plant for the Continuous Casting of Special Steels. J. Seloron. (*Mét. Constr. Mécan.*, 1955, **87**, May, 361–367). A description is given of the development and operation of a continuous-casting plant at the Unieux works of C.A.F.L., France. The plant is capable of casting 25 tonnes/day. Comparison is made between the operation of this plant and those in the U.S.A. Only special steels are cast and they include steels of the tool, stainless, high-temperature, magnetic, and non-forgeable types. The plant has been in satisfactory operation for two years.—B. G. B.

Continuously Cast Wide Range of Alloy Steels. J. Seloron. (*Iron Age*, 1955, **175**, Feb. 24, 88–90). A brief description is given of continuous casting at the Jacob Holzer Works of Compagnie des Ateliers et Forges de la Loire, Unieux, France. Highly alloyed steels, including stainless, heat-resisting, electrical, and tool steel grades, are being economically cast into sound oval-shaped billets on a limited production basis (1 ton/hr.).—D. L. C. P.

Report of the Sub-Committee on Semi-Killed Steels. Donney and Duflot. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (5), 1001–1005). The uses of semi-killed steels, particularly in thin plate where segregation should be avoided, are mentioned, and typical analyses are given. Details of charge refining and additions to the bath required in their manufacture are suggested, and methods of casting are outlined. Defects which can occur in rolled products are given.—T. E. D.

Hydraulic Integrator for Solving Problems in the Heating and Cooling of Cylindrical Bodies and Its Use in the Investigation of the Solidification of Steel Ingots in Moulds. A. A. Skvortsov. (*Liteinoe Proizvodstvo*, 1953, (7), 15–20). [In Russian]. A hydraulic integrator for studying heat conduction in cylindrical bodies is described and a detailed account is given of its application to the investigation of the solidification of a cylindrical steel casting. In the integrator internal resistance to heat flow was represented by the resistance to the flow of water of porcelain tubes. The external resistance to heat transfer was represented by that of a clip which could be adjusted over a wide range. Calculated and experimental results are compared for several seconds.—S. K.

Reusable Hot Tops Proven Successful in Ingot Pouring Practice. J. C. Carpenter. (*J. Met.*, 1955, **7**, Jan., Section 1, 24). In U.S. works trials, the use of "C & D" floating hot tops lined with insulating firebrick has resulted in an increase in ingot yield of 3% over normal practice, with comparable ingot quality. The insulating brick is re-usable when protected with a ½-in. refractory wash.—G. F.

Statistical Analysis of Subsurface Blowhole Defects in Steel Ingots. T. Okawa, K. Abe, and Y. Hatta. (*Sumitomo Metals*,

1954, **6**, Jan., 28–34). [In Japanese]. The surface scarfing method may be used to give an accurate estimate of the number of blowholes. Variations in the number may occur between the surfaces of an ingot, between the positions on the stool, and between stools. The minimum number of ingots to be tested for each heat may be determined statistically.

PRODUCTION OF FERRO-ALLOYS

Production of Low-Carbon Ferro-Chrome. A. B. Chatterjea, G. P. Contractor, and B. R. Nijhawan. (*Trans. Indian Inst. Met.*, 1953, **7**, 45–60). Attempts were made to reduce chromite ore containing 53% Cr_2O_3 and 15% FeO chiefly with ferro-silicon containing 73–79% silicon with a view to produce low-carbon ferrochrome. Melts were made in a 10-lb. 17-kVA. indirect-arc rocking-type furnace. It was observed that silicon was not completely efficient as a reducing agent, as 15% Cr_2O_3 was contained in the slag and only 64% chromium was recovered. Increasing the basicity of the slag slightly lowered its Cr_2O_3 content. Slag basicity index of 1–1·2 resulted in a clean separation of the alloy. The addition of aluminium towards the end of the process lowered the amount of Cr_2O_3 in the slag, increased silicon in the ferroalloy, and substantially raised the recovery of chromium.—D. H.

Calcium–Silicon and Multiple-Component Alloys on Calcium–Silicon Basis. E. Steffen. (*Stahl u. Eisen*, 1955, **75**, Feb. 24, 221–222). The author describes briefly the production of calcium–silicon alloy of nominal composition 60 : 30, balance impurities, mainly iron. The deoxidation effect of calcium–silicon is greatly improved by addition of aluminium; alloys with a nominal aluminium content of 10%, 20%, and 30% are marketed under the name Alcasil.—T. G.

Solubility of Oxygen in Liquid Nickel and Fe–Ni Alloys. H. A. Wriedt and J. Chipman. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**; *J. Met.*, 1955, **7**, Mar., 477–479). The authors describe the apparatus and methods used in their determination of oxygen solubility in liquid nickel and nickel–iron alloys. The results are tabulated and discussed.—G. F.

Equilibrium between Titanium in Liquid Iron and Titanium Oxides. R. L. Hadley and G. Derge. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**; *J. Met.*, 1955, **7**, Jan., Section 1, 55–60). The authors have measured the amounts of oxygen in liquid iron–titanium alloys containing up to 50% Ti, and have determined the oxide phases in equilibrium with these alloys, using TiO_2 crucibles. At 1600° C., the Fe–Ti–O system can be represented on a ternary isotherm. The solubility of oxygen at this temperature decreases to a minimum of about 0·003% with < 1% Ti.—G. F.

Oxygen Solubility and Oxide Phases in the Fe–Cr–O System. D. C. Hilty, W. D. Forgeng, and R. L. Folkman. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**; *J. Met.*, 1955, **7**, Feb., Section 1, 253–268). The solubility of oxygen in liquid Fe–Cr alloys has been determined at 1550°, 1600°, and 1650° C. for alloys containing up to 50% Cr. The solubility decreases as chromium increases to 6%, then increases gradually. Phase relations in the Fe–Cr–O system are evaluated and are represented on ternary diagrams. Two previously unreported oxides have been identified as primary phases.—G. F.

The Effects of Sulphur, Selenium, and Tellurium on Graphite Formation in an Fe–C–Si Alloy. S. Garber. (*J. Iron Steel Inst.*, 1955, **181**, Dec., 291–302). [This issue].

FOUNDRY PRACTICE

An Automatic Foundry System. (*Machinery*, 1955, **86**, June 24, 1402–1403). The Osborn Mfg. Co., Cleveland, Ohio, have recently developed a fully automatic foundry system. The automatic unit is capable of producing 300 moulds per hour with a casting weight of between 1 oz. and 2½ lb.—M. A. K.

Mechanized Foundry at Lichfield. (*Mech. Handling*, 1955, **42**, May, 260–264). The paper describes the production methods employed at the newly mechanized foundry of Chamberlin and Hill Ltd., Lichfield, with particular emphasis on the specialized mechanical-handling equipment used.—D. H.

The Influence of Layout and Mechanization on Production Costs in a Medium-Sized Foundry. P. Tincolini. (*Fonderia Ital.*, 1955, **4**, Jan., 29–32). [In Italian]. The author describes briefly the case history of a medium-sized foundry producing 300–500 tons of castings per month in sizes ranging from 1 kg. to 20 tons. Through a reorganization of materials flow, the foundry was able to introduce substantial economies.

New Proposal for the Standardization of Grey Cast Irons. A. Collaud. (*Fonderia Ital.*, 1955, **4**, Apr., 193–204). [In Italian]. The author reviews the specifications adopted for grey irons in different countries and remains of the opinion that a unification of specifications for grey iron is impracticable. A classification of castings by size and specifications for cooling techniques are likely to produce better practical results.—M. D. J. B.

Investigation of the Vertical Movement of Metal during Flow in the Mould. T. P. Yao. (*Giesserei*, 1955, **44**, Mar. 31, 145–153). Metal flow in moulds is first considered theoretically, including the effects of gas pressure, hydrodynamic " water-hammer," " water-fault," the formation of pressure waves, and the influence of the change in properties of the flowing metal. A series of experiments has been carried out using glass moulds with mercury as the metal, other experiments were carried out using a sand mould to investigate the theoretical effects. The results indicate that the flow of metal in a mould is generally subjected to a whirling motion, the main influences being: (1) the gas pressure, due to mechanical compression and thermal expansion of the trapped air and gases liberated from the mould; (2) the " water-hammer " effect, due to the change in cross-section and contour of the mould; (3) the " water-fault " effect caused by the impact of two or more currents of metal in the mould.—R. J. W.

Efficiency and Productivity in the Foundry. D. H. Soeter. (*Metalen*, 1955, **10**, June 15, 173–179). [In Dutch]. A paper read before the International Foundry Congress held at Florence putting forward ideas from a Dutch viewpoint on the attainment of efficiency and productivity in the foundry.

New Type of Ladle. I. I. Sankov. (*Liteinoe Proizvodstvo*, 1953, (6), 10–13). [In Russian]. Experiments are described which showed that the extent of slag contamination of cast iron leaving the ladle can be considerably decreased by using a syphon tube, the immersed end of which is close to the ladle-bottom. Fireclay tubes were found to have a satisfactory life.—S. K.

Foundry Technical Centre. (*Aciers Fins Spéc. Franç.*, 1954, Dec., 11–15). The Centre is a co-operative research organization financed by all those firms engaged in this industry; a survey is presented of its activities, which include not only scientific research but also technical advice, circulation of information, etc.—E. A. C.

Sampling for Simplified Scrap Control. D. J. Kaufman and R. E. Johnston. (*Amer. Foundryman*, 1955, **27**, Mar., 46–49). Quality control in a jobbing foundry is outlined and it is concluded that a trained inspector can operate a successful scrap-control programme without using statistical quality-control charts. A suitable sampling procedure is discussed.

Re-designing of Steel Castings to Ensure Soundness and Reduce Costs. T. Hurst. (*Found. Trade J.*, 1955, **98**, Apr. 21 421–425; Apr. 28, 453–458). The problems involved in redesigning castings to give greater soundness are discussed with reference to examples from railway, rolling-mill and general engineering practice. The necessity for close co-operation between designers and foundrymen is stressed and the advantages of cast/weld construction are considered.—B. C. W.

Non-destructive Testing Aids Casting Design. R. H. Herrmann. (*Foundry*, 1955, **83**, Mar., 84–87). A description is given of the procedure used at the Superior Steel and Malleable Castings Co., Benton Harbor, Mich., to develop a suitable casting design for a given part. Sample castings are stressed using a brittle lacquer or strain gauges to determine the suitability of the design.—B. C. W.

The Use and Care of Crucibles. W. M. Halliday. (*Foundry*, 1955, **83**, Mar., 106–109). The precautions that should be observed in using graphite crucibles in pit-type and tilting-type furnaces are discussed in detail.—B. C. W.

How Redesign Boosted Strength of Cast Iron Compressor Cylinder. T. H. Burke. (*Iron Age*, 1955, **175**, Feb. 10, 100–103). An investigation is described into the strength of compressor-cylinder casting requiring working pressures of 1200 lb./sq. in. Material, foundry practice, and heat-treatment were examined. The results have allowed a high-strength cast-iron design to be used in place of a steel casting.—D. L. C. P.

Cast Ferrous Metals. I. Choice of Materials is Vital. II. What Physicals can you Expect ? III. What Are Their Performance Limits ? IV. What Can You Do About Flaws ? T. E. Eagan. (*Steel*, 1954, **135**, Nov. 15, 158–162; Nov. 22, 112–114; Nov. 29, 80–82; Dec. 6, 158–162).

Twice Daily Casting in Average Iron Foundries. (*J. int. tech. Indust. Fond.*, 1954, Nov.-Dec., 7–10). The operation of cupolas in iron foundries of average size for casting twice

daily is described. A saving in coke by this technique is achieved.—B. G. B.

Machining Costs of Iron Castings Cut With Cupola Deoxidation Process. (*Western Metals*, 1953, **11**, Oct., 66–68). The use of a briquetted deoxidizer, "Ferrocarbo," a product of the Carborundum Co., is discussed. Added on the basis of 1% of the metal charge, notable improvements in machinability of grey iron are obtained, and at the same time silicon and manganese contents can be reduced.—P. M. C.

Optimum Thermal Conditions for Melting in a Cupola with a Fore-Hearth. A. N. Antonov. (*Liteinoe Proizvodstvo*, 1954, (9), 26–27). [In Russian]. Experiments on a 900-mm. dia. cupola are described in which considerable economies of coke and increases in production were obtained. The optimal operating conditions established enabled cast iron with temperatures of 1320–1410° C. to be produced.—S. K.

How to Maintain Bed Height During a Cupola Heat. W. J. Estes. (*Amer. Foundryman*, 1955, **27**, Mar., 42–44). Experiments with coke charges of increasing weight designed to maintain a constant coke-bed height during cupola melting are described.—B. C. W.

Importance of Air Preheat in a Cupola Working For the Foundry Industry. E. Löbbecke and C. Chiabotti. (*Fonderia Ital.*, 1955, **4**, Jan., 39–42). [In Italian]. The authors examine the influence of preheat and show that this is more than a means of economizing coke. Cupolas with preheat become furnaces in which it is possible to regulate reactions between metal, slag, and gas and so modify the nature of the burden both chemically and physically.—M. D. J. B.

Melting with Slow-Reacting Coke. W. Heinrichs. (*Giesserei*, 1955, **42**, Mar. 3, 102–106). Suggestions are given on the use of the new high-carbon coke in the foundry. A series of experiments has been carried out in which "HC-coke" is compared with normal coke for use in the cupola. The former shows appreciably higher melting efficiency. Comparative curves are given for sulphur pickup and silicon loss. Compared with ordinary foundry coke HC-coke has a much higher density, and a lower porosity and specific internal surface. The use of this coke in the foundry will be dependent upon the price.—R. J. W.

Metallurgical Blast Cupola Offers Improved Melting Efficiency. S. T. Jaswinski. (*Iron Age*, 1955, **175**, Apr. 21, 87–91). The operation and advantages of the metallurgical blast cupola are described. It combines the operating characteristics of the blast-furnace with the low-pressure blast and continuous tapping features of the conventional cupola.

Selective Absorption of Phosphorus by Steel in the Acid-lined Cupola Furnace. W. S. Williams. (*Iron Coal Trades Rev.*, 1955, **170**, May 20, 1163). During the author's experiments on oxygen-lancing of steel melted in an acid-lined cupola furnace, difficulties were experienced with high phosphorus contents in the product. The author indicates how the cause was traced to a cumulative and progressive extraction of phosphorus by the steel from the slag on the cupola walls and bed coke. The use of a relined cupola overcame the difficulty.—G. F.

Cast High Strength Irons To Standard Stock Sizes and Shapes. O. Smalley. (*Iron Age*, 1955, **175**, Apr. 21, 100–102). Points of importance in the growing practice of stocking standard cast bars and other shapes for quick delivery are mentioned.—D. L. C. P.

Resistance to Wear of High-Quality Cast-Iron Parts for Tractors and Internal Combustion Engines. B. N. Seredenko. (*Liteinoe Proizvodstvo*, 1954, (8), 3–6). [In Russian]. The results are reported of a comprehensive investigation carried out over five years on the resistance to wear of specimens and actual parts cast from high-quality cast irons, grey irons, babbit metal, and various steels. The tests were intended to evaluate the wear-resistance suitability of these materials for use in tracked vehicles and in internal combustion engines. Tests were carried out for dry and lubricated frictions for friction with quartz sand. The results show that castings of high-quality iron with spheroidal or lamellar graphite are entirely satisfactory. Comparative wear-resistance figures are given for the wide variety of materials tested.—S. K.

Alloyed Grey Cast Iron. H. Poetter. (*Technik*, 1955, **10**, Mar., 137–144). The purpose of the article is to help the designer to choose the cast iron most appropriate to his purpose. The effect of additions of various elements on the properties of cast iron is discussed first, followed by a description of a wide range of alloy irons together with typical applications. A bibliography of 35 references is appended.

Appearance of Brittleness in High-Strength Irons. N. G. Girshovich and M. P. Simanovskii. (*Liteinoe Proizvodstvo*, 1954, (8), 12–14). [In Russian]. An account is given of the investigation of the appearance of brittleness in high-strength iron castings, analogous to temper-brittleness in steel. Preliminary experiments were made to find the effect of temperature on impact strength from 20° to 800° C. Subsequently the effect of heating on toughness of ferritic high-strength iron was studied over a wide temperature range (100–850° C.) with soaking at the heating temperature for 1 and 10 hr. followed by air cooling. Cooling was carried out at various rates, and the best effects were obtained with rapid cooling from temperatures of about 700–750° C.—S. K.

Oxide Skin Formation on Pig Iron and Cast-Iron Melts. R. Merz and B. Marinček. (*Stahl u. Eisen*, 1955, **75**, Feb. 24, 196–199). The knowledge of the composition of pig iron is not sufficient for an appraisal of its suitability in the foundry or converter. The authors studied the formation, breaking up, and disappearance of the oxide skin on iron melts and its effect on the quality of the castings produced and on the behaviour of the iron in the converter for a number of pig irons and silicon irons. The oxide skin appears with decreasing temperatures and disappears with rising temperatures. High temperatures, low sulphur, low manganese, high carbon, low silicon, and low phosphorus contents counteract oxide skin formation.—T. G.

Orientated Segregation of Secondary Graphite in Grey Cast Iron. W. Hofmann and J. M. Sistiaga. (*Arch. Eisenhüttenwesen*, 1955, **26**, Feb., 109–112). Orientated segregation of secondary graphite was observed in a cast-iron evaporator for caustic soda. Segregation could also be produced by heating the material to 850° C. for long periods *in vacuo*. The graphite segregation is parallel to the $\{111\}$ plane of the austenite. Austenite single crystals grown from the melt of the same material did not show graphite segregation on heating to 850° C. The authors discuss the phenomena involved.—T. G.

Titanium in Cast Iron. G. F. Comstock. (*Foundry*, 1955, **83**, Apr., 118–123).

Ductile Iron as Die and Mold Castings Offers Hardening, Welding, Machinability Advantages. M. Asimow. (*Western Metals*, 1953, **11**, Nov., 50–53). The great improvement in mechanical properties of ductile iron (in which the graphite is spheroidized by a magnesium addition) over normal grey cast iron is discussed.—P. M. C.

The Theory of Spheroidal Cast Irons. P. Ryš. (*Slévárenství*, 1955, **3**, (4), 101–110). [In Czech]. On the basis of a critical analysis of existing theories, the view that spheroidal graphite is formed from supersaturated austenite is rejected in favour of direct formation from the melt.—P. F.

Spheroidal Cast Irons. A. M. Plešinger. (*Slévárenství*, 1955, **3**, (4), 97–101). [In Czech]. A survey of past developments and probable future scope of inoculated cast irons is given, with special reference to recent advances and estimated requirements in Czechoslovakia.—P. F.

Surface Tension of Cerium-Treated Cast Iron. R. Gautschi and B. Marinček. (*Giesserei*, 1955, **42**, Mar. 17, 121–123). The production of spheroidal graphite cast iron by treatment with cerium is first described. The surface tension of the melt was measured by the capillary depression method both before and after the cerium treatment for three series of melts. After treatment an increase in the surface tension was observed in all cases, amounting to 50% in favourable cases. This increase was found to correspond to a decrease in the sulphur content. Repetition of surface tension measurements indicated an accuracy of $\pm$ 5% was obtained.—R. J. W.

Grain Structure in Fractures of Uninoculated and Inoculated Cast Irons. A. V. Bobrov and S. T. Kiselev. (*Liteinoe Proizvodstvo*, 1954, (9), 20–22). [In Russian]. This is an account of a metallographic study and theoretical discussion of grain structure found in fractures of uninoculated and inoculated cast irons. X-ray examination yields data which indicate that the grains of inoculated irons, including those inoculated with magnesium, are more monolithic than those of uninoculated irons. Experiments were carried out to confirm that the ferrite in magnesium-inoculated iron consists of blocks of α-iron and finely-dispersed carbides, which are not revealed by normal etching on polished specimens, and that the relative carbide content is higher than in grey iron.—S. K.

Effect of Oxidation of Cast Iron on Inoculation. B. V. Stark and N. K. Nekrasov. (*Liteinoe Proizvodstvo*, 1954, (9),

18–20). [In Russian]. An investigation on the influence of preliminary oxidation and deoxidation of cast iron on the effect of its inoculation with 75% ferrosilicon is reported. The final composition of all specimens was about 3·27% C and 1·20% Si, two specimens being cast from each melt produced in uncalcined magnesite crucibles. The oxidation was carried out by adding mill scale; the deoxidation with aluminium, and the resulting hardness and microstructures were compared with each other and with those of untreated specimens, for silicon additions of 0, 0·2%, and 0·4% in each case.—S. K.

Strength of Cast Iron with Spheroidal Graphite. I. V. Kudryavtsev and N. B. Baranova. (*Liteinoe Proizvodstvo*, 1954, (9), 6–10). [In Russian]. An account is given of mechanical tests on a series of cast irons with spheroidal graphite with compositions in the following range: 2·54–3·1% total C, 1·79–3·25% Si, 0·26–0·71% Mn, 0·002–0·048% S, 0·02–0·22% P, 0–0·097% Mn, 0–0·18% Cr, 0–0·20% Ni. Tests were made on specimens as cast and after various heat-treatments; using static, cyclic, and impact loads; at room temperatures and up to 700° C.; in air and in corrosive media. The iron was produced in a cupola or electric furnace. Results of corresponding tests on cast iron with lamellar pearlite and a carbon steel are given for comparison.—S. K.

Resistance to Wear of Cast Iron with Spheroidal Graphite. A. D. Ushakov and K. M. Khrushcheva. (*Liteinoe Proizvodstvo*, 1953, (7), 21–23). [In Russian]. In the investigation described the behaviour of inoculated cast iron in dry and in lubricated friction was studied. Specimens were prepared from inoculated cast iron and were subjected to various heat-treatments before testing. The microstructures and mechanical properties are tabulated and test results are compared with those for bronze and brass. High-strength inoculated cast iron with up to 40% ferrite was found to be wear resistant. Surface hardening followed by hardening and high-temperature tempering increased resistance to wear without decreasing anti-friction properties.—S. K.

An Efficient Method of Inoculating Cast Iron. A. F. Durnienko. (*Liteinoe Proizvodstvo*, 1953, (6), 9). [In Russian]. A brief note is given on the inoculation of cast iron with magnesium by the use of a magnesium–ferrosilicon alloy.

Effect of Carbon and Silicon on the Spheroidizing of Graphite in Magnesium-treated Iron. M. Okamoto and R. Yoda. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, Sept., 422–425). [In Japanese]. With additions of approx. 0·5% Mg, the matrix assumed a structure of pearlite and ferrite when [C] + [Si] > 7%. Increase of C content led to more and larger nodules; of Si content, more but smaller nodules. Both desulphurization and decarburization in the melt, due to Mg, were promoted by increase in C or Si content.—K. E. J.

Pinholding on Nodular Iron Castings. J. Gittus. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1955, **5**, Apr., 594–603). A study has been made of the sub-surface "pinholes" sometimes found in magnesium-treated nodular iron castings. The defect appears to be most pronounced in greensand-moulded castings and can be alleviated both by additions of carbonaceous materials to the mould and by small additions to the metal of aluminium, tellurium, and bismuth. A cerium addition is made to cancel any harmful effect due to these latter elements.

Tensile and Fatigue Tests on Hardened and Tempered Nodular Irons. G. N. J. Gilbert and K. B. Palmer. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1955, **5**, Apr., 604–615). Some published results on the mechanical properties of hardened and tempered nodular irons are reviewed. Tests have been carried out on a 2% silicon nodular iron in the as-cast and hardened and tempered conditions. The material was hardened by quenching in oil from temperatures of 900° and 850° C. Tensile results on bars tempered between 600° and 400° C. for times up to 4 hr., and unnotched and notched fatigue results on specimens tempered for 2 hr. at 600° and 550° C. are presented.—B. G. B.

Pearlitic Malleable: Casting for Tougher Jobs. A. G. Gray. (*Steel*, 1955, **136**, Jan. 10, 62–63). Information on pearlitic iron castings is summarized: extent of present production and utilization; production methods; properties. Its applications are increasing. The most popular production method involves an arrested heat-treating cycle. The limited ductility of this stronger material can be acceptable.—D. L. C. P.

Pearlitic Malleable: A Case History. (*Steel*, 1955, **136**, Jan. 10, 64–65). Tests leading to the acceptance of pearlitic malleable iron for casting the bearing journal box of rail wagons are described.—D. L. C. P.

Annealing Furnaces for Malleable Iron. N. V. Sadin. (*Liteinoe Proizvodstvo*, 1954, (9), 12–14). [In Russian]. The effect of annealing on the structure of malleable cast iron is considered together with the performance of different types of annealing furnaces.—S. K.

Inoculation of Malleable Iron with Aluminium and Ferrotitanium. B. F. Sobolev. (*Liteinoe Proizvodstvo*, 1953, (6), 19–22). [In Russian]. Experiments are described on the inoculation of malleable cast iron with aluminium and ferrotitanium with the object of increasing the number of centres of graphitization during annealing. Titanium was added either as the metal or as ferrotitanium (17% Ti, 6·7% Al). The effect of various additions of inoculators on the following were studied: mechanical properties; kinetics of graphitization; hardness of the iron during the main period of pearlite decomposition; the ferrite portion of the iron; the quantity and distribution of temper carbon; austenite grain size. Conditions for annealing inoculated and uninoculated castings are compared. The ranges of addition of inoculators are given.—S. K.

Manganese Spheroidized Malleable Iron. I. I. Khoroshev (*Liteinoe Proizvodstvo*, 1953, (7), 26–29). [In Russian]. The object of the investigation described was the determination of the optimum conditions for the production of high-quality spheroidized malleable cast iron. Specimens were cast of an iron with the following initial composition in the liquid state: 2·5–2·8% C, 0·9–1·2% Si, 0·4–0·6% Mn, up to 0·16% S, and up to 0·12% P. Varying manganese contents were produced by addition of ferromanganese, and spheroidization was carried out under various conditions. Optimum mechanical properties were obtained when the percentage of manganese was the sum of 0·7 times the silicon content and twice the sulphur content. Inoculation and heat-treatments under various conditions were tested.—S. K.

Precision Alloy Steel Castings. (*Metallurgia*, 1955, **51**, May, 235–238). A description is given of a precision process developed by B.S.A. Tools Ltd. for casting alloy steel. The process was originally used for the manufacture of milling cutters but the scope has increased and some examples of its latest application are shown.—B. G. B.

Economic Production of Steel Castings for Armatures. J. Přibil. (Reports of Czechoslovak Foundry Research, Appendix to *Slévárenství*, 1955, **3**, (4)). [In Czech]. Details are given of improved methods of risering and chilling, resulting in substantial savings in production.—P. F.

Experimental Production of Acid-Resistant Steel Castings for the Cellulose-Paper Industry. L. M. Postnov. (*Liteinoe Proizvodstvo*, 1954, (8), 7–8). [In Russian]. Experiments showed that high-quality castings of acid-resistant steel can be produced by conventional methods.—S. K.

Defects in Steel Castings. R. A. Boustred. (*Found. Trade J.*, 1955, **98**, Mar. 24, 311–319). The factors affecting blowholes, shrinkage defects, metal penetration, hot-tears and scabs in steel castings are enumerated and discussed.—B. C. W.

Production of Large Steel Castings. J. B. Mohler. (*Foundry*, 1955, **83**, Mar., 113–115). The procedures used at the New Castle, Pa., plant of the United Engineering and Foundry Co. to produce castings of up to 240 tons in weight are described.—B. C. W.

Steel Penetration. R. C. Emmons and J. Bach. (*Foundry*, 1955, **83**, Apr., 108–116). The results of an investigation into the penetration of steel into dry sand moulds are presented and discussed. It was found that the gas in the sand after pouring was nearly all carbon monoxide and hydrogen and that penetration took place at a sand temperature of about 1000° C. It is suggested that in a reducing atmosphere silica is removed from the sand by the formation of a hydrate leaving voids which are filled by metal penetrating as a carbonyl. Subsequent penetration by molten steel may follow the channels established in this reaction. If the metal is oxidized by moisture or carbon monoxide the oxide will wet the silica and enable small pores to be penetrated. Iron oxide will also react with silica to form the low-melting-point silicate, fayalite, which will encourage further penetration. The authors conclude that as pressure is essential for the formation of the silica hydrate and the iron carbonyls metal penetration may be prevented by a high-permeability sand or by venting.—B. C. W.

Zirconium Sand, a New Material for Foundries. E. Vergari.

(*Fonderia Ital.*, 1955, **4**, Apr., 215–222). [In Italian]. Zirconium sand (a silicate of zircon, $ZrSiO_4$) has the following approximate analysis: zircon oxide 66% min., silica 33·5% max., titanium oxide 0·3% max., iron oxide 0·1% max., and alumina 0·1% max. The foundry properties of this sand are discussed in detail as well as its practical applications. Different mixtures to be used with zirconium sands are specified.—M. D. J. B.

On the Relation between the Viscous and Mechanical Properties of Bentonites. H. Siegel. (*Giesserei*, 1955, **42**, Apr. 14, 176–186). The physical testing of a number of different bentonites is described and the relationships between the compression strength and the moisture content at 20° and 105° C. established. The drying process and its dependence on time are described and the relation between gas permeability and initial moisture content and dryness given. Relationships are established between the mechanical strength, the swelling capacity, and the viscosity.—R. J. W.

A New Binder for Moulding Material. H. Busch. (*Giesserei*, 1955, **42**, Apr. 14, 187–191). Moulding material in general, comparisons between different binders, the dependence of strength and gas permeability on the baking temperature, and the preparation of cores and moulds using infra-red drying are discussed. The pouring of castings and experiments with the pouring spiral are described with examples. Finally, a cost comparison is made.—R. J. W.

The Influence of Atmospheric Conditions on the Measured Results in Mould Sand Testing. W. Patterson. (*Giesserei*, 1955, **42**, Mar. 31, 159–161). The effect of moisture content on such properties as the compression strength and gas permeability are discussed at length. The relative humidity and temperature of the air affects the test specimens appreciably. Data are given for moisture contents corresponding to different relative humidities. Graphs are presented for the water lost during the grinding of a glauconite natural sand and for the increase in weight of a previously dried bentonite specimen exposed to the air. It is recommended that the water content of each specimen tested be determined.—R. J. W.

Rapid Measurement of Mould Face and Core Moisture Content after Drying. M. Houšt. (*Slévárenství*, 1955, **3**, (5), 135–138). [In Czech]. A simple battery-fed apparatus for measuring electrical conductivity is calibrated as a mould and core hygrometer.—P. F.

A Study of the Use of Clays, in the Plastic State, in Moulding Sands for Cast Iron. V. Lo Ré. (*Bol. Assoc. Brasil Met.*, 1955, **10**, July, 241–250). [In Portuguese]. Locally obtained clays were homogenized and added, whilst in the plastic state, to mixes for moulding sands. The properties of these mixes were compared with those obtained by the conventional use of dry clay powders and found to be similar. The results of tests using either new or reclaimed sands are given and it is pointed out that there is a definite economic advantage in the use of plastic-state clays for bonding, especially since there are no difficulties in this technique.—P. S.

Reproducibility of Core Sand Tests. O. J. Myers. (*Amer. Foundryman*, 1955, **27**, Feb., 54–63). The variables associated with routine tensile and bakability tests on core sands are reviewed and discussed in detail together with the methods used to minimize their effects.—B. C. W.

Advantages of Automatic Moisture Control. W. E. Patterson. (*Amer. Foundryman*, 1955, **27**, Feb., 48–49). An automatic sand-tempering unit applied to a skip-hoist system is briefly described. The advantages of the system are improved casting quality, increased production, and decreased sand-mill maintenance.—B. C. W.

Reclaiming Core Sand. W. D. Dunn. (*Foundry*, 1955, **83**, Mar., 90–95). A description is given of the core sand reclamation system installed at the Oberdorfer Foundries Inc., Syracuse, N.Y. The sand passes through a breaker barrel, calciner, cooler, and a two-stage sand-classifying system after which it is ready for re-use.—B. C. W.

Increasing the Works Efficiency in Pattern Construction. F. Lamm. (*Giesserei*, 1955, **42**, Apr. 14, 201–203). The correct additions to be made to the labour force are first discussed, and the checking of the throughput in the workshop considered. Methods of mechanizing the shop are described and illustrated, this latter being essential for increased efficiency.

The Scum Riser. A Contribution to Gating and Casting Technique. L. Frede and W. W. Magers. (*Giesserei*, 1955, **42**, Mar. 17, 135–138). This paper describes a film in which flow processes are illustrated in a casting system, use being made of models. The efficiency of scum risers depends on the height of the cast metal, the position of the runners and outlets and on their relative diameters. The flow patterns in various different arrangements are illustrated. The change in direction in a channel is considered separately, particular reference being made to the effect of curvature on the flow of fluid.—R. J. W.

High-Pressure or Heat-Insulated Risers? S. Šimoník. (*Slévárenství*, 1955, **3**, (4), 114–116). [In Czech].

Steel Facing of Aluminium Coreboxes. (*Found. Trade J.*, 1955, **98**, Apr. 14, 407).

Corner Joints for Core-Boxes. V. Toman and J. Grgurić. (*Slévárenství*, 1955, **3**, (5), 141–142). [In Czech]. The design and use of pre-fabricated screw-attached metal clamps are described. Wood consumption is considerably reduced.—P. F.

Casting Steel Pots for Metallurgical Use. T. R. Stanley. (*Amer. Foundryman*, 1955, **27**, Feb., 42–46). A description is given of methods used to produce large cast containers for handling molten lead and red-hot slag.—B. C. W.

Rothfischer Centrifugal Iron Pipe Casting Machines. (*Machinery*, 1955, **86**, May 13, 1034–1036). The article describes a range of machines designed for the centrifugal casting of iron main and waste water-pipes, and bushes manufactured by Gebr. Rothfischer, 13a Stornstein, bei Neustadt-Waldnaab, Germany.—M. A. K.

Design and Production Notes on Precision Investment Casting. (*Mech. World*, 1955, **135**, Jan., 23–25). A brief description is given of investment casting with particular reference to the suitability of various metals for the process.

Production of Complex Tools by Precision Casting. O. Morávek. (*Slévárenství*, 1955, **3**, (5), 138–140). [In Czech]. The technology of the lost-wax method is discussed, suitable wax mixtures are specified and applications instanced. Finely ground quartz sand in a methanolic solution of ethyl silicate was used as mould material. The ethyl silicate is replaceable by water-glass.—P. F.

Vacuum Furnace Capacity Easily Expanded with Modular Units. R. G. Ulrech. (*Iron Age*, 1955, **175**, Apr. 14, 100–102). It is suggested that users may require to increase the size of vacuum-melting and casting equipment after installation due to expanding use of the process. Modular type vacuum-furnace equipment is described.—D. L. C. P.

Some Uses of Silica Sols in Precision Investment Casting. D. J. Cloherty and H. G. Emblem. (*Indust. Chem.*, 1955, **31**, Mar., 111–114). The use of a sodium silicate solution (0·08 N) as a binder for a pattern investment slurry is described. Addition of silica sol permits the production of moulds with intricate cored passages. Viscosities of slurries and strengths of moulds are given, and the procedure for producing a Rolls-Royce Nene guide vane is described.—T. E. D.

A Study of Investment Materials. H. O. McIntyre. (*Foundry*, 1955, **83**, Mar., 96–99). The factors which must be considered in choosing an investment material are discussed. Among the aspects considered are the grading of the investment, the amount of expansion during heating, the possibility of physical changes on heating, and the properties of the investment binder.—B. C. W.

Precision Alloy Steel Castings. (*Machine Shop Mag.*, 1955, **16**, Feb., 80–85). The article describes a process developed by B.S.A. Tools Ltd. for the precision casting of milling cutters, in which the resulting metallurgical structure and mechanical properties very closely resembled those of conventional type of high-speed steel. The advantages include improved design and considerable reduction in cost.—M. A. K.

Some Developments in the Art of Casting Metals and Alloys. L. W. Pateman and J. B. Rait. (*Rev. Mét.*, 1955, **52**, Jan., 33–46). Recent developments in casting metals are reviewed, attention being principally focused on the production and examination of steel-castings. Certain specialized techniques such as precision casting by the lost-wax process and centrifugal casting are described in detail and examples given. Reference is also made to more recent progress in the classical methods of casting.—G. E. D.

Thompson Products Adopts Low Cost, High Quality Shell Mold Casting Process. W. Achor. (*Western Metals*, 1953, **11**, Oct., 72–74). The Croning or "C" process for the production of precision castings is briefly described, and the adoption of the method for the production of compressor valves, guides, and seat inserts by Thompson Products, California, is outlined and the various stages illustrated.—P. M. C.

Shell Moulding. F. K. Shallenberger. (*Product Eng.*, 1955,

26, Mar., 175–179). The general advantages of shell moulding, with particular reference to the economic use of this method for short production runs are discussed in this article. Twelve specific guides to produce minimum cost castings are given.

Shell Mould Line Expands Malleable Castings Output. R. H. Herrmann. (*Foundry*, 1955, **83**, Apr., 90–95). The new and completely integrated shell-moulding system at the Indianapolis foundry of the Link-Belt Co. is described. The system produces 180 moulds per hour and uses four station rotary machines for making and closing shell moulds.—B. C. W.

Pontiac Foundry Goes Automatic. (*Steel*, 1955, **136**, Feb. 7, 79–80). The operation of the automatic foundry for Pontiac car parts is explained. Cylinder blocks and heads, and many other parts are produced. Automatic sand-mould making machines and simplification of cores have allowed greatly increased output with less manpower.—D. L. C. P.

Modern Facilities Incorporated In New Ingot Mould Foundry. E. Bremer. (*Foundry*, 1955, **83**, Mar., 100–105). The layout, equipment, and foundry practice at the new ingot-mould foundry of the United States Steel Corp. at the Edgar Thomson Works, Braddock, Pa., is described.—B. C. W.

Factors Influencing the Chilling of Cast Iron. W. J. Williams. (*Metallurgia*, 1955, **51**, June, 273–279). The chilling characteristics of cast iron are influenced by the nature of the charge, melting conditions, and melting and casting temperatures, as well as by chemical composition. Work done by the B.C.I.R.A. on this subject is discussed, reference being made to the effect of inoculation and of the oxygen normally present in low-silicon irons.—B. G. B.

On the Inverse Chill Phenomencn of Cast Iron. M. Homma and M. Hirata. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **6**, June, 268–273). [In Japanese]. The factors leading to inverse chilling (viz. chemical composition, cooling rate and O_2 content) are discussed; the importance of minimizing oxygen absorption during melting is emphasized.—K. E. J.

The Investigation of Cast Iron. IV. The Freezing Process of Rapid Cooled Cast Iron. I. Igarashi, G. Ôhira, and T. Horigome. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, July, 324–328). [In Japanese]. Rapid freezing of cast iron resulted in formation of primary austenite, secondary cementite, and ledeburite from hypoeutectic iron, but primary austenite alone from hypereutectic iron. Similar structures were found in the Al–Si, Al–Fe, Sn–Bi, and Cd–Bi systems. The results are discussed in terms of velocity of crystallization and solubility of Fe in cementite.—K. E. J.

The Investigation of Cast Iron. V. The Solidification Process of Cast Iron. I. Igarashi, G. Ôhira, and T. Horigome. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, Sept., 425–428). [In Japanese]. Studies of hypoeutectic Fe–C alloys, with parallel work on the Al–Si system, demonstrated the primary formation of austenite dendrites, then, at eutectic, the supersaturated austenite which deposited cementite leading immediately to the flaky graphite structure.—K. E. J.

Sinking Under Bosses on Thin Plates: Preliminary Experiments on Foundry Variables. I. C. H. Hughes. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1955, **5**, Apr., 616–627). Some effects of melting and pouring temperatures, inoculation with ferro-silicon, moulding practice, and design variables upon sinking under bosses in plates $\frac{3}{16}$ in. and $\frac{5}{16}$ in. thick have been studied using an iron of composition: total carbon 3·1–3·2%, silicon 2·5–3·0%, manganese 0·6–0·7%, sulphur 0·07–0·08%, phosphorus 1·1–1·2%.—B. G. B.

HEATING FURNACES AND SOAKING PITS

A Dual-frequency Heat Installation for Steel Billets. (*Machinery*, 1955, **86**, June 3, 1210–1212). This type of installation, manufactured by Société Général d'Applications Electro-Thermique (S.G.A.E.T.), has recently been supplied for heating steel billets, 95 mm. dia. × 215 mm. to forging temperature. The hourly output is 150 billets serving a single forging press.—M. A. K.

Induction Heating in Industry. A. F. Leatherman. (*Battelle Tech. Rev.*, 1955, **4**, May, 53–57).

Thompson Forging Operations Employ Induction Heating for Operating Economy. P. Miller. (*Western Metals*, 1953, **11**, Jan., 58–60). The major benefits of induction heating for forging are discussed in an account of the Thompson Products, Inc., plant, California. The company forges engine valves, aircraft parts, bolts, and alloy steel rings. Tecco induction heating units are used for all heating operations.

Push-type Furnaces at Sollac. Rosier. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (4), 829–831). Three-zone Rust type heating furnaces are briefly described. The instrumentation in each zone is mentioned.—T. E. D.

The Siemens Furnace at Rondange. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (4), 825–828). A furnace for heating billets from cold to about 1200° C. at a rate of 60 tons/hr. is described. Operating data are listed for heating billets for rolling to various products. Sectional drawings of the furnace are given.—T. E. D.

The Wire-Mill Furnace at the Chiers Works at Longwy. Collard. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (4), 811–816). A push-type billet heating furnace which will heat billets 50 mm. × 50 mm. or 63 mm. × 63 mm. by 9 m. to 1200° C. at a rate of 40 tons/hr. is described. These are fed to a Morgan continuous mill. The fuel supply system and furnace design are illustrated and described, including the dimensions, hearth and roof refractories, burners, recuperators, and Cowpers. Instrumentation and safety devices are mentioned. Performance data in heating different size billets are given.—T. E. D.

The Sheet-Mill Furnace at the Chiers Works at Longwy. Collard. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (4), 805–809). The design and details of control of a push-type slab reheating furnace are illustrated and described. The two-zone heating system, which allows atmosphere control, permits the heating of 60 tons/hr. of slabs to 1200° C. The hearth and roof refractories, the recuperators for both air and gas, and draught control are mentioned. Instruments fitted to the furnace are listed. Characteristic operating data for heating various size slabs for producing various size sheets are given.—T. E. D.

The Push-Type 45 tons/hr. Billet Furnace for the Merchant Bar Mill at Homécourt (Sidelor). Couturier. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (4), 817–824). The details of construction, dimensions, and automatic regulation of the furnace are given. The low turbulence burners, with mixed coke-oven and blast-furnace gas, give a heating rate of 350 kg./hr. per sq. m. of surface, at 45 tons/hr. The heat balance is given at different operating rates, and the effect of two zones, the calorific value of the gas, and combustion control are discussed.—T. E. D.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Heat Treatment Service for Tool Makers. (*Metalworking Prod.*, 1955, **99**, May 6, 798–800). A new heat-treatment division of Uddeholm Ltd. established at Birmingham has recently been opened. It features 8 independently controlled furnaces of 4 types, 4 tanks for oil and water quenching, and low-temperature oven, with comprehensive electrical equipment.—M. A. K.

Using Dew Point for Automatic Control of Heat Treatment Atmospheres. P. Trippe. (*Metalworking Prod.*, 1955, **99**, May 13, 861–863). A recently developed system claims to facilitate automatic control of furnace atmosphere in heat-treatment processes by detecting and controlling the dew-point and therefore the carbon potential.—M. A. K.

New Bar Heat Treatment Plant. (*Metallurgia*, 1955, **51**, June, 265–266; *Iron Coal Trades Rev.*, 1955, **170**, June 3, 1287-1288; *Brit. Steelmaker*, 1955, **21**, July, 229–230; *Indust. Gas*, 1955, **18**, July, 310–312). A description is given of a new heat treatment plant of Sanderson Brothers and Newbould Ltd.—B. G. B.

Some Recent Furnace Installations. (*Metallurgia*, 1955, **51**, June, 283–300). Examples are given from the wide range of heat-treatment plant and equipment which were installed during 1954.—B. G. B.

Automatic Furnace Line Highly Versatile In Forge Shop Heat Treating. W. F. Herdrich. (*Steel Processing*, 1954, **40**, Nov., 723–726, 728). An automatic heat-treating line, incorporating a direct gas-fired pusher tray hardening furnace, a recirculating oil-quench tank with conveyor, discharging to a unique high-temperature (pull-through type) recirculating tempering furnace is described and illustrated. The plant, which handles forgings from $2\frac{1}{2}$ to 75 lb. in weight, was designed and built by Surface Combustion Corporation. Full performance data are presented.—P. M. C.

Furnace Atmosphere Heat-Treating Problems. Practical Application of Equilibrium Curves. N. K. Koebel. (*Metal Treatment and Drop Forging*, 1954, **21**, Dec., 549–554). The

author discusses the limitations of theoretical equilibrium curves and concludes that they have little value in practical heat-treatment where it is desired to obtain precise results for carbon control. Practical equilibrium curves relating dew point to carbon content of carbon, alloy and tool steels at various temperatures, and obtained by direct measurement of results from industrial furnaces using endothermic atmospheres, are discussed. The use of these practical curves is explained, and rules for their application are given.—P. M. C.

Heat-Treatment of Steel. W. F. Brandsma. (*Metalen*, 1955, **10**, June 30, 241–246). [In Dutch]. The influence of the various components of iron and steel originally present as impurities and of added alloying substances during heat-treatment over different temperature ranges is discussed at length together with the resultant effects on the austenite, ferrite, cementite, and martensite phases. Reference is also made to the alloying of steels, the choice of materials for particular purposes, weldability, and the enhancement of permissible stresses in alloy and heat-treated steels.—F. R. H.

Heat Treatments Standardize Part Structures for Automated Machining Lines. W. J. Behrens. (*Iron Age*, 1955, **175**, Apr. 28, 95–97). The special arrangements for metallurgical control in a highly mechanized plant producing universal joints and propeller-shaft components are described. All raw materials are heat-treated in automatic furnaces.

New Heat-Treatment Plant for Steel Bars: Modernization of Sheffield Works. (*Iron Coal Trades Rev.*, 1955, **170**, May 13, 1109–1110; *Brit. Steelmaker*, 1955, **21**, June, 192–193; *Engineer*, 1955, **199**, May 13, 676; *Machinery*, 1955, **86**, May 13, 1063–1064, 1067; *Metalworking Prod.*, 1955, **99**, May 13, 864–865). The modernization of the Sheffield works of Arthur Balfour and Co., Ltd., includes three new batch-type gas-fired bar annealing and heat-treatment furnaces, with an electric charging machine and two fabricated steel loading tables. Details of the new plant are given.—G. F.

The Transformation of Steels by Rapid Heating. K. Yokota and N. Iguchi. (*Waseda Univ., Rep.*, 1955, Jan., 10 pp.). The results of rapid heating of steel (at rates up to 500° C./sec.) were followed dilatometrically; they confirm that abnormal structures (e.g. in zones adjacent to welds) as well as those caused by rapid cooling may be explained on the basis of diffusion of C and other elements. Particularly in steels containing up to 0·4% of C, the temperature at which some transformations occur is greatly affected by heating rates and diffusion velocities, and the Ac_3 point may be elevated almost indefinitely. A mechanism of the $\alpha \rightarrow \gamma$ transformation is suggested. The Ac_1 transformation is also affected by temperature, i.e. by the rate at which C atoms can diffuse into ferrite.—K. E. J.

Rapid Methods for Heat-Treating Steel Castings. Ya. A. Smolyanitskii. (*Liteinoe Proizvodstvo*, 1953, (7), 30–31). [In Russian]. A four-stage rapid method for the heat-treatment of steel castings is proposed. The first stage consists in a rapid heating to a temperature 150–300° C. above Ac_3. In the second the casting is cooled to 100–150° C. below Ar_1, until the surface first shows darkening. Thirdly, the casting is again heated to 30–80° C. above Ac_3. Finally, the casting is cooled to 350° C. in the furnace (for annealing) or in still air (for normalization). The method was tested with specimens of a steel (0·34% C, 0·19% Si, 0·86% Mn, 0·045% P, 0·052% S), and found satisfactory.—S. K.

The Phenomena of Flame-Hardening Represented in a *TTT* Diagram for Continuous Cooling. A. Rose and L. Rademacher. (*Stahl u. Eisen*, 1955, **75**, Feb. 24, 199–210). The authors studied heating and cooling of steel (37 MnSi 5 and Ck 45) specimens during flame-hardening. Thermocouples were inserted in the specimens at various depths and the flame-hardening equipment passed over the specimens at various speeds. The results obtained are presented in *TTT* diagrams. Hardening depends on the temperature distribution across the section and on the transformation rate of the steel. Temperature distribution is mainly a function of the speed of the burner over the specimen and of the distance between burner and water jet. The experiments included the use of a number of burners and water jets.—T. G.

Heat Treating Tool Steels. I & II. Water Hardening Types. III & IV. Oil and Air Hardening Types. V. Hot Work and High Speed Types. H. C. Manley and G. E. Brumbach. (*Steel*, 1955, **136**, Jan. 24, 70–73; Jan. 31, 72–74; Feb. 7, 111–114; Feb. 14, 87–90; Mar. 14, 106–109).

Controlled Atmosphere Heat Treating. H. M. Heyn. (*Steel*, 1954, **135**, Nov. 22, 96–98; Nov. 29, 72–74). A brief general description is given of the theory and practice of controlled-atmosphere heat treating. A table summarizes the effect of several types of atmosphere on various metals.—D. L. C. P.

Alcohol Makes a Furnace Atmosphere. M. J. Stutzman. (*Steel*, 1955, **136**, Jan. 17, 94, 96). The use of vaporized alcohol–water mixtures for heat-treating-furnace atmospheres is described. Atmospheres rich in hydrogen and carbon monoxide can be made; changes are easily effected by changing the proportions of the solution. Advantages are simplicity and low cost of equipment.—D. L. C. P.

Europe's Largest Furnace for Continuous Gas Carburizing. T. E. W. Preston. (*Metalworking Prod.*, 1955, **99**, July 8, 1205–1212). A new three-tracked furnace, designed and built by Electric Resistance Furnace Co., Ltd., is now in service on a production basis at Dagenham works of Ford Motor Co., Ltd. It is thought to be the largest of its type and uses a gas-fired radiant-tube heating system, while the furnace atmosphere is an externally generated carrier gas of controllable carbon potential, to which small, controlled additions of hydrocarbon are made. Depth of case is controlled by carrier dew-point selection.—M. A. K.

Some Considerations on the Action of Energisers in Solid Carburising Agents. H. Schrader. (*Trans. Indian Inst. Met.*, 1953, **7**, 61–80). The types of common additions used for solid carburizing agents are discussed. Comparative experiments with different energizer additions have confirmed that the energizing effect of calcium carbonate is markedly lower than barium carbonate. Oxides are less effective than the carbonates. Addition of chlorides resulted in a poor energizing action. The energizing effect of free nitrogen is strong and comparable to that of the most effective carbonate energizer. The energizing effect of oxides and carbonates depended on the oxygen content introduced by the energizer and the heat required to dissociate them to the metallic state, and for the formation of alkali and alkali-earth carbides. The action of nitrogen energizers has been attributed to the formation of iron carbonitrides and of γ-iron when nitrogen is absorbed by α-iron. This allows carburization at lower temperatures and increases carbon pickup at high temperatures.—D. H.

Fundamental Study on Mild Carburization. IV. E. Fuji. (*Nippon Kinzoku Gakkai-Si*, 1951, **B, 15**, Sept., 415–419). [In Japanese]. Studies of various compounds showed that the Na_2CO_3–CaO system was excellent as a promoter for mild carburization of plain C steel. Eleven types of promoter for chromium steel were examined in the temperature range 920–980° C. for times of 5–10 hr.—K. E. J.

Soft Nitriding, a Process for Improving the Wear-Resistance of Steel Surfaces. J. Müller. (*Metalloberfläche*, 1955, **9**, Apr., B52–B55). The process of "soft nitriding" (the nitriding of plain carbon steels), although not increasing greatly the hardness of the steel, is shown to increase substantially the wear resistance of the steel. Examples of the application of the process are given.—L. D. H.

The Mechanism of Accelerating Action of NH_4Cl Upon Solid Diffusion. E. Yajima. (*Nippon Kinzoku Gakkai-Si*, 1951, **B, 15**, June, 249–253; 253–257). [In Japanese]. In the diffusion of Al into steel, the accelerating action of NH_4Cl is effective with amounts of approx. 0·1–0·2%, and activation occurs at 220–240° C. The NH_4Cl is adsorbed at lower temperatures, and assists diffusion by enabling $AlCl_3$ to be formed in the powder and dissociated on the steel. The H_2 gas liberated also assists the diffusion process.—K. E. J.

The Structure of Surface Layers Hardened by Spark Treatment. M. Čermak and E. Pokorný. (*Hutnické Listy*, 1955, **10**, (4), 215–221). [In Czech]. Results obtained in a study of the effect of electrode composition on hardening showed that electrodes consisting of sintered carbides (TiC 25%, WC 75%) were best, alloying of the surface with the electrode material taking place. Fatigue resistance was reduced by the hardening treatment.—P. F.

Steel Castings for Flame Hardening. H. W. Grönegress. (*Giesserei*, 1955, **42**, Apr. 14, 170–175). The composition of typical steels used for flame-hardening are given and considered in relation to their strength properties. The hardenability testing apparatus and the heat-treatment are described, together with rim decarbonization. Finally, practical examples of the use of steel castings to be flame-hardened are given. These include chain sprockets and links, gear wheels, and crane parts.—R. J. W.

Oxyacetylene Flame Hardening. (*Aciers Fins Spéc. Franç.*,

1954, Dec., 52–61). A brief description is given of the equipment used, and of its operation. The operating method is determined by the geometry of the part being treated, and four possible methods are given for a cylindrical specimen. Details are also given of the hardening of several machine parts, one of which is a screwdown shaft.—E. A. C.

Surface Hardening of Ferritic Malleable Iron during High-Frequency Heating. M. O. Rabin and K. Z. Shepelyakovskii. (*Liteinoe Proizvodstvo*, 1954, (9), 10–12). [In Russian]. The surface hardening of ferritic malleable cast iron to a degree approximately equal to that of hardened pearlitic cast iron is considered. An essential feature is that sufficient time must be allowed for diffusion of carbon from its "nests," and, compared with the high-frequency induction-hardening of steel, the time for ferritic malleable iron is tens of times greater ($\lesssim$ 70 sec.) and the temperature considerably higher (1100–1150° C.). The effects of various hardening conditions on the microstructure of samples are illustrated, and the application of H.F. hardening to various parts and the special inductors by which it can be effected with full utilization of generator capacity are described.—S. K.

Carbonitriding: Various Techniques for Casehardening Steel. F. Schulte. (*Iron Coal Trades Rev.*, 1954, **169**, Oct. 22, 973–982). The author discusses techniques for case-hardening steel, with particular emphasis on carbo-nitriding. The effects of time, temperature, and gas composition on the properties and composition of the case are described, and details are given of the types of furnace used.—G. F.

An Attempt at Preparation of Nitriding Steel by Solid Diffusion of the Special Elements. T. Sato and E. Yajima. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, July, 297–301). [In Japanese]. Diffusion rates of both Cr and Al into C steels were increased by the presence of the other elements. On steels containing diffused Cr and Al an experimental case was obtained by NH_3 nitriding.—K. E. J.

Continuous Carbonitriding Setup Promotes Safety, Uniform Quality. R. J. Belz. (*Iron Age*, 1955, **175**, Feb. 17, 95–97). An arrangement at Gemmer Mfg. Co., Detroit, is described; by integrating an atmosphere hardening furnace with an automatic quench, wash, and draw, high quality, uniformity and safety have been achieved on steering gear components.

The Carbonitration Process. L. G. W. Palethorpe. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Jan., 21–28). The advantages of the technique are described and examples of its use are given. The influence of the concentration of ammonia in town gas on the surface structure is shown by a series of photomicrographs of etched specimens. The preparation of the required gas composition on an industrial scale is described, together with furnaces for carrying out the heat-treatment.

Continuous Annealing of Steel Strip—Controls for a High Speed Line. H. C. Morrow. (*Mech. Eng.*, 1954, **76**, Dec., 990–994). The author describes equipment for the continuous cleaning and annealing of steel strip 0·0076–0·015 in. thick and 18–37 in. wide at speeds up to 1000 ft./min. Full details are given of the electrolytic cleaning plant, the winding and unwinding gear, and the gas-fired radiant-tube heating furnace. The process is fully instrumented and the control gear is described.—D. N.

Low-Temperature Annealing after Cold Working. The Hardening of Pure Metals. I. T. Sano, H. Ichikawa, K. Nishimoto, and N. Nakanishi. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, Oct., 453–457). [In Japanese]. Investigations into anomalous hardness produced in cold-worked metals by annealing below the recrystallization temperature included work on chemically pure Fe, etc. Generally, a reciprocal relationship exists between time to reach maximum hardness and absolute temp. With Fe, the hardness was greater than that obtained by water-quenching from high temperatures and ageing at the same temperature. The phenomenon is therefore not entirely explained by precipitation effects.

The Third Transformation During Annealing of Steel. V. G. Permyakov. (*Zhur. Tekhn. Fiz.*, 1955, **25**, (5), 908–915). [In Russian]. Processes taking place during annealing of steel with particular reference to the third transformation in the temperature region 300–400° C. were investigated using sensitive magnetometric and dilatometric methods. It is concluded that the third transformation is based on the reaction: Fe + C → intermediate carbide, which on heating above 400° C. is transformed into cementite. The composition and properties of intermediate carbide phases require further investigation.—V. G.

Short Cycle Anneal Restores Ductility in Cold Extrusions. C. A. Turner, jun. (*Iron Age*, 1955, **175**, Mar. 10, 96–99). The latest techniques for making low-carbon 2·75 in. rocket heads at Heintz Mfg. Co., Philadelphia, are described. Quick annealing treatment is used; parts are passed in a few seconds through radiant-heated furnaces held above the annealing temperature, and the result is equivalent to a long soak.

Restore Surface Carbon in Sub-Critical and Over-Critical Anneal. J. D. Armour. (*Iron Age*, 1955, **175**, Feb. 24, 83–85). It is described how a continuous pusher, tray-type controlled atmosphere furnace is used at Republic Steels Union Drawn Steel Div., for continuous large scale annealing of cold-drawn rod and wire in coils.—D. L. C. P.

Isothermal Hardening of Alloy Tool Steel. Yu. A. Geller. (*Stanki i Instrument*, 1954, (10), 16–19). [In Russian]. In the investigation described the respective applicabilities of isothermal and other hardening techniques to the hardening of tool steels were studied.—S. K.

New Unit for Tool Steels in Birmingham. (*Iron Coal Trades Rev.*, 1955, **170**, May 13, 1113–1114). A new heat-treatment division of the Swedish company of Uddeholm Ltd. has been opened in Birmingham. Details are given of the equipment for salt-bath hardening of tools and dies; batch-furnace hardening, pack carburizing, and annealing of tools; and oil and water quenching.—G. F.

Small Parts Hardened to Precise Limits in Sealed, Batch-Type Furnaces. W. G. Patton. (*Iron Age*, 1954, **174**, Dec. 2, 120–121).

Salt Quench Aids Dimension Control. H. Gearhart. (*Steel*, 1954, **136**, Mar. 7, 104–105). The best conditions found for quenching high-manganese oil-hardening tool-steel punches and dies are specified. By martempering at 50° F. below the steel's M_S point little trouble is experienced from distortion and growth.—D. L. C. P.

The Relations between Heat-Treating Temperature and Cutting Properties of Cutlery Steels. S. Koshiba and K. Tanaka. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, Nov., 531–534). [In Japanese]. Tests were made with a specially designed apparatus. Optimum quenching temp. is approx. 780° C., and cutting properties decrease with increase of tempering temperature. Raw materials made from iron sand imparted good qualities.—K. E. J.

Studies on Quenching Media. I. Apparatus and Method of Research. II. Observation of the Cooling Process in Quenching by Moving Picture. M. Tagaya and I. Tamura. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, Nov., 535–537; 538–541). [In Japanese]. A thermoelectric apparatus is described which ensures high sensitivity and good reproducibility for cooling curves. The evolution of gas, and liquid convection were observed during quenching by photographing the specimen and its shadow, in media such as water, oil, aq. NaCl and water-glass. In general, cooling proceeds in four stages: (*a*) liquid in contact heats to its b.p., (*b*) from a vapour film, (*c*) from boiling liquid, and (*d*) by convection currents.—K. E. J.

Studies on Quenching Media. III. Theoretical Study of Cooling Process during Quenching. M. Tagaya and I. Tamura. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, Dec., 589–594). [In Japanese]. The four different stages found in liquid quenching are analysed in detail; the cooling properties of a liquid largely depend on the "characteristic temperature," i.e. that of breakdown of the vapour film on the metal. The ideal medium must allow molecules to be adsorbed, have a low vapour pressure, and have "characteristic temperature" of > 700° C. and b.p. of approx. 300° C.; the type and dimensions of the steel, however, are also important.—K. E. J.

Improvement of Cold-Worked Metals by "Strain Tempering." K. Iwase and T. Sano. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, Oct., 503–504). [In Japanese]. Laboratory tests on piano wire showed that substantial improvements in the tensile and torsional properties of cold-worked material could be achieved by heating for a short period during which a force exceeding the yield stress was applied.—K. E. J.

Mechanised Austempering Line Shortens Heat-Treating Time. H. K. Jameson. (*Iron Age*, 1955, **175**, Mar. 24, 100–101). Improved results are reported following the introduction of an automatic sequence for heat-treating steel wrench and tool parts.—D. L. C. P.

FORGING, STAMPING, DRAWING, AND PRESSING

Hammers and Presses for the Stamping of Heavy Forgings. W. Wroblewski. (*Hutnik*, 1955, **22**, (4), 127–130). [In Polish].

Driving Drawing Presses. (*Machine Shop Mag.*, 1955, **16**, Mar., 161–164). The actual drawing operation in a press cannot be speeded beyond a definite maximum. Any increase in production of a drawing press can be gained only by reducing the idle time, i.e. during the return stroke of the ram and during the first part or the approach portion of the down stroke. The ways in which this can be done are analysed in this article.—M. A. K.

Power Press Safety. J. H. Price. (*Welding Metal Fab.*, 1955, **23**, Mar., 82–85).

The Giant in the Forge. W. A. Hawkins. (*Vickers Mag.*, 1955, Spring, 17–22). A description is given of the manufacture of forged boiler drums of 4–5 in. wall thickness for use in high-pressure steam generation. The drums are forged in one piece from 275-ton ingots.—B. G. B.

Study of Forgeability. Very. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (4), 783–800). The control of the forging properties of stainless and high-temperature steels is examined. Two tests are used and compared from the point of view of control testing. Apparatus is described and results are given graphically and pictorially. It is concluded that the shock test is more suitable for control purposes.—T. E. D.

Production of Rear Axle Shafts by Electric Upsetting. (*Machinery*, 1955, **87**, July 8, 84–86). Some details are given of an installation, now in the U.K., for the production of flanged half-shafts for motor-car rear axles, using electric upsetting machines manufactured by the German firm of Hasenclever.—M. A. K.

Drop Forging in the Railway Industry. (*Metal Treatment Drop Forg.*, 1954, **21**, Oct., 469–476; Dec., 555–562). The article describes in some detail the forging practice of British Railways (Midland Region). Carriage and wagon forgings are produced at Derby, and locomotive forgings at Crewe. The facilities, methods, and products of each plant are described, particular attention being paid to the reclamation of scrapped material and vehicles, modified methods of manufacture to effect economies, and rates of output.—P. M. C.

Manufacture by Pressing of Objects Having a Complex Shape. R. Dupas. (*Mét. Constr. Mécan.*, 1955, **87**, May, 397–403). The design and use of moulds for pressing sheet metal into complex shapes are discussed.—B. G. B.

Presses Duplicate Machining Accuracy in Forming Stator Rings. H. Chase. (*Iron Age*, 1955, **175**, Mar. 24, 102–104). The arrangements are described whereby steel rings for Buick torque converters are pressed to extremely close tolerances. Output is 250 parts per hour.—D. L. C. P.

The Principles of Mounting Moulds in Hammers. W. Wroblewski. (*Hutnik*, 1955, **22**, (1), 13–20). [In Polish].

Stainless and Nickel Alloys Require Stronger Dies. S. R. Cope. (*Metalworking Prod.*, 1955, **99**, July 8, 1226–1228). Chromium–nickel stainless steel, nickel, and high-nickel alloys require larger presses with twice the power used in working ordinary steel. The author discusses the increase in die wear and recommends materials which give satisfactory results.

Cold Power Spinning will Save Material and Cut Costs. K. W. Stalker and K. W. Moore. (*Metalworking Prod.*, 1955, **99**, July 1, 1173–1178). A recent development in cold working permits making hollow, symmetrical parts, either tubular or conical, from simple blanks. Procedure is similar in many respects to that of hand spinning except pressures up to 400,000 lb./sq. in. are used to 'roll-flow' the metal along a mandrel. Usually, the article is completed in one pass along the spinning rollers.—M. A. K.

Solve Special Shell Problems with Proved Die Design Methods. S. R. Cope. (*Metalworking Prod.*, 1955, **99**, June 17, 1102–1105). The author outlines the rules to be followed for producing shells with corrugations, two levels, or pockets, with standard die design.—M. A. K.

How to Make Shells With Ribs, Bosses and Projections. S. R. Cope. (*Metalworking Prod.*, 1955, **99**, June 3, 984–987). The author describes methods of working out a series of operations which allows proper flow of metal for complicated pressings.—M. A. K.

Special Shells, Standard Draw Practice. S. R. Cope. (*Metalworking Prod.*, 1955, **99**, Apr. 15, 682–684). The possibility of making special shells feature by feature using standard methods are discussed. Normal procedure for drawing can be applied to obtain blank sizes, radius, operation sequence, and suitable dies.—M. A. K.

How to Understand Cold Working of Metals. S. Storchheim. (*Metalworking Prod.*, 1955, **99**, May 13, 845–851). Plastic deformation of primary products into finished parts with the minimum of machining is now being developed. The article discusses the factors involved with reference to effects of prior processing on the metal, its grain structure, work-hardening rate, etc., in order to estimate the effects to mechanical and other properties when a material is cold-worked.—M. A. K.

Studies in Cold Drawing. I. Effect of Cold Drawing on Steel. H. Majors, jun. (*Trans. Amer. Soc. Mech. Eng.*, 1955, **77**, Jan., 37–48). The effect of the amount of reduction and the direction of drawing per pass on the hardness, residual stressing, microstructure, and the torsional and tensile strengths of S.A.E. 1020 steel rod was determined. Exploratory work was conducted on the influence of prior cold work and fatigue stressing on the brittle transition temperature. Effects of size, machining, and time after cold work on the tension and torsional properties were observed. Cold-drawing is compared with cold-rolling.—D. H.

New Deep Drawing Method Gives 30% Cost Savings in Tooling and Machining. H. W. Young. (*Western Metals*, 1953, **11**, Jan., 62–64). The Hydroform deep drawing process is described. The process eliminates expensive and matching die sets, the part being formed by hydraulic fluid behind a rubber lamination which moulds the blank around a single die member. Examples of the work done by a 12-in. Cincinnati Hydroform press are described and illustrated.—P. M. C.

Deep-Drawing Research at the Metal Research Institute TNO. J. H. Zaat. (*Metalen*, 1955, **10**, May 15, 117–121; May 31, 140–146). [In Dutch]. A survey is given of the research project on deep-drawing conducted at the Metal Research Institute TNO followed by a short review of sheet-metal testing methods and a more extensive description of a test method developed at the institute.—F. R. H.

Variations in Wall-Thickness in Tubes During Drawing. B. Počta. (*Hutnické Listy*, 1955, **10**, (4), 94–99). [In Czech]. The theory of tube drawing and cross-rolling is developed and supported by experimental data on the variation of wall thickness with drawing conditions. With an initial wall thickness to tube diameter ratio of 0·17 the wall thickness remains invariant on drawing; with a larger ratio the wall thickness is larger after drawing than before, and with a smaller ratio the opposite holds. These results are relevant in precision-tubing manufacture. Hot and cold drawing are considered.—P. F.

Make Small Shells in Progressive Dies. S. R. Cope. (*Machinist*, 1955, **99**, Feb. 25, 338–341).

Research on the Cold Drawing of Mild-Steel Tubes. III. T. Okamoto. (*Sumitomo Metals*, 1955, **7**, Jan., 1–16). [In Japanese]. Formulæ for drawing stress and tube stress in tube sinking are evolved, based on wire-drawing theory but allowing for die angle and wall thickness. Formulæ are also given for drawing stress and plug stress in plug drawing, for the particular case where tube internal diameter is kept constant, and the general case where the tube diameter and wall thickness are both reduced.—K. E. J.

Progressive Dies Can Make Deep Shells. S. R. Cope. (*Machinist*, 1955, **99**, Apr. 1, 593–596). Successful dies for small shells are designed by paying attention to how the partially formed part is held in the strip and the proper use of pressure pads, locating punches, idle stations, and either downward or upward drawing. For further information see earlier instalment XXII (*Machinist*, 1955, **99**, Feb. 25, p. 338).

Research on Cold Drawing of Mild-Steel Tubes (II). T. Okamoto. (*Sumitomo Metals*, 1954, **6**, Apr., 85–102). [In Japanese]. By stopping tubes half-way through drawing, studies were made on the influence of die angle, tube size, and reduction in area on the changes of wall thickness and the difference between the inside diameter of the die and the outside diameter of the tube. The effects of die form and steel properties, and some abnormal cases of tube sinking were also investigated. Deformation was found to occur at the inlet and outlet as well as in the die itself, and various critical conditions were established.—K. E. J.

The Case of the Snapping Shells. H. J. Pessl. (*Steel*, 1954, **135**, Dec. 6, 122). Trouble was experienced with 75-mm. shells inexplicably splitting round the circumference while being drawn. Eventually the punch split and was found to have been growing as a result of an internal flow and fatigue fracture.—D. L. C. P.

Bethlehem Triples Wire Mill Capacity with New Machines and Furnaces. (*Western Metals*, 1953, **11**, July, 60–61). A

brief illustrated account is given of a new wire production unit at the Los Angeles plant of Bethlehem Pacific Coast Steel Corp.—P. M. C.

Continuous Gauging of Wire by the Pneumatic Solex Method. H. Schulz. (*Draht, German ed.*, 1955, **6**, Apr., 134–136). The principles of pneumatic gauging are explained and instruments for the gauging of moving wire, as designed and manufactured by Solex, are described and illustrated. The non-contact gauge is said to be limited to wires larger than 0·090 in. dia.; contact gauges pneumatically controlled offer greater flexibility.—J. G. W.

Borax in the Wire Industry. A. Zastera. (*Draht, German ed.*, 1955, **6**, Mar., 82–85). Following an outline of the physical properties of borax, particulars are given of borax baths and dipping times for wire, and results are quoted of laboratory experiments in which coat thicknesses and compositions were determined. The method of analysis is described.—J. G. W.

Cold Extrusion of Shells. E. Olsen. (*Machinery*, 1955, **86**, May 27, 1148–1150). The article describes the cold-extrusion of 60-mm. smoke and explosive shells carried out at works of Oliver Corporation, Springfield, Ohio. The press operations number five, with two annealing operations. The only machining required is drilling, facing, and tapping for the fin, turning the bourrelet, and machining the nose for the fuze.—M. A. K.

A New Approach to Metal-Forming Problems. Experimental Stress Analysis for a Tubular Extrusion. E. G. Thomsen. (*Trans. Amer. Soc. Mech. Eng.*, 1955, **77**, May, 515–522). An incremental inverted extrusion process was used to obtain the magnitude and direction of particle velocities in a billet during the pressing of a tubular product of commercially pure lead. It was found that both axial stresses and mean pressures in the region of the die were higher on the extrusion axis and near the cylinder wall than in the central region of the billet. This stress distribution is appreciably different from that of a solid extrusion for the same reduction in area.—D. H.

Contributions to the Knowledge of Pressure Measurements During Metal Deformation. J. Frisch. (*Trans. Amer. Soc. Mech. Eng.*, 1955, **77**, May, 509–513). Two pressure-measuring devices using SR.4 strain gauges and steel pins of $\frac{1}{8}$ and $\frac{1}{4}$ in. dia., respectively, were inserted in the wall of an extrusion cylinder. The mean pressure and radial wall stresses were measured during the extrusion of commercially pure lead and found to be in close agreement with calculated values.—D. H.

Extrusion of Arc Welding Electrodes. D. M. Archer. (*Canad. Metals*, 1955, **18**, Apr., 58–60).

ROLLING-MILL PRACTICE

Modern Rolling Mills Aid Study of High Strength Materials. J. S. McMartin. (*Iron Age*, 1955, **175**, June 23, 104·106). The design of rolling mills built specifically for investigation purposes is considered.—D. L. C. P.

Extension During Temper Rolling: Continuous Measurement Achieved by New Instrument. (*Brit. Steelmaker*, 1955, **21**, Mar., 88–91). The Baldwin Instrument Co., Ltd., has developed an instrument which measures, without contact, the extension or reduction given during temper-rolling to an accuracy of $\pm \frac{1}{8}\%$, which is described.—G. F.

Hot Rolling With the Planetary Mill: Success at Ductile Steels Ltd. H. M. Walter. (*Iron Steel*, 1955, **28**, Feb., 68–71; Mar., 106–108). The author first discusses the rolling theory of the planetary mill and then reviews experience gained to date with the first planetary mill erected in Europe, at Ductile Steels Ltd. A comparison with conventional rolling practice is also made.—G. F.

Hot Rolling: A Study of Draught, Spread, and Elongation. Z. Wusatowski. (*Iron Steel*, 1955, **28**, Feb., 49–54; Mar., 89–94). The author determines the correlations between draught, spread, and elongation, depending on the initial shape of the bar and roll diameter for hot-rolled low-carbon steels, taking into consideration the influence of temperature, roll velocity, steel composition, and roll surface condition.

Study on the Hot-Working Properties of Rimmed Steel. II. T. Ikeshima and T. Morishima. (*Tetsu to Hagane*, 1955, **41**, Apr., 430–435). [In Japanese.] Black spots which act as defects in hot working were found to contain approx. 0·15% S and 0·4% Mn, with many sulphide inclusions. Further tests showed that hot-working properties of steel were impaired when the S content exceeded 0·15%. Increase of Mn content, however, improved the workability of high-S steel. Some FeS inclusions were found in black spots; heating at 800–1200° C. for several hours effected conversion from FeS to MnS.

The Use of Slide Rules in the Calculation of Z. Wusatowski Formulæ. Z. Wusatowski. (*Metallurgie*, 1955, **5**, May, 169–171).

Dependence of Coercive Force on Thickness of Iron–Silicon Alloy. Yu. P. Budrakova and V. V. Drukhinin. (*Zhur. Tekhn. Fiz.*, 1955, **25**, (1), 108–111). [In Russian]. The above dependence was investigated using transformer steel sheets and single crystals. An increase of coercive force with a decrease in specimen thickness is the same and independent of the method used for decreasing the thickness (rolling or dissolving). This indicates that an increase of the coercive force in thin sheets (0·05–0·1 mm.) in relation to thick sheets (0·35–0·50 mm.) is not related to additional technological operations involved, but is due to some differences in the process of over-magnetization.—V. G.

The Position of the Flow Point in Hot and Cold Rolling. Z. Wusatowski. (*Metallurgie*, 1955, **5**, Mar., 103–114). Various methods of calculating the angle are described in detail. In cold rolling, the Orowan or Bland and Ford methods are recommended, or, where speed is more important than accuracy, the Pawlow, Ekelund, or Siebel methods. In hot rolling, the Orowan and Pascoe methods are to be preferred to the Pawlow method.—L. J. L.

Investigations of Hot and Cold Rolling with Drag Rolls and the Determination of Roll Slippage from Forward Slip. W. Lueg and K. H. Treptow. (*Stahl u. Eisen*, 1955, **75**, Apr. 7, 391–401). Rolling force and power input are compared in hot and cold rolling with driven rolls and with a drag roll and found to be almost identical. Mild-steel strip, 2 and 20 mm. thick, for cold and hot rolling, respectively, was used. The steels had a yield strength of 25·2 and 28·4 and an U.T.S. of 35·3 and 41·0 kg./sq. mm., respectively. Forward slip was measured by impressions from the rolls and there was a marked difference between the faces in contact with the driven roll and with the drag roll. The distribution of strain in hot rolling was studied by the displacement of plugs inserted in the plate. It was found that the centre-line remains in position but that there is a heavy displacement of material on the face in contact with the driven roll.—T. G.

Inhomogeneous Deformation during the Temper-Rolling of Annealed Mild Steel. B. B. Hundy. (*J. Iron Steel Inst.*, 1955, **181**, Dec., 313–315). [This issue].

Inhomogeneous Deformation in Rolling and Wire-Drawing. B. B. Hundy and A. R. E. Singer. (*J. Inst. Metals*, 1954–55, **83**, May, 401–407). Microhardness measurements made on copper, brass, aluminium, and mild steel indicate that there is an analogy between the inhomogeneity of deformation in rolled strip and that in drawn wire. It is possible to control to some extent the degree of inhomogeneity in worked metals. There is no surface-hardening in strain-aged mild steel, and secondary inhomogeneity should have a relatively minor effect on the mechanical properties compared with that of the total plastic deformation.—B. G. B.

The Determination of Productive Capacity in Rolling Mills. W. Dams. (*Met. u. Giesserei Techn.*, 1951, **1**, Mar., 88–89).

Experience with Plastic Bearings in Rolling Trains at the VEB Steel Works and Rolling Mill "Wilhelm Florin," Hennigsdorf. R. Politz. (*Metallurgie*, 1955, **5**, May, 152–157).

New Features in the Design of Rolling Mills. M. Neumann. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (3), 609–632). The requirements for a roll bearing are discussed, and a design is given for a bearing, suitable for the upper roll of a two-high mill, which can be kept clean and well-lubricated and will not permit horizontal movement of the roll. The balancing of blooming-mill rolls is mentioned, and the design for a 1100-mm. dia. roll mill is shown. Other equipment described includes roll-straighteners, rotary bar shears, and wire finishing stands.—T. E. D.

Temperature Rise of Surfaces in Rolling Contact. T. Nishihara and K. Endo. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1952, **1**, Mar., 52–56). [In Japanese]. The maximum temperature rise on surfaces in rolling contact is calculated, with simple assumptions, from the load, sliding speed, heat conductivity of the metal, coefficient of friction, etc. The results agree with observations using thermocouples.—K. E. J.

Roll Knurling at South Works of U.S. Steel. E. M. Benedict. (*Iron Steel Eng.*, 1955, **32**, Apr., 57–60).

Bearing Maintenance for Economy. J. A. Toth. (*Iron Steel Eng.*, 1955, **32**, Feb., 64–68).

The Suitability of Emulsion Lubricants in the Cold Rolling of Strip Steel. H. Panner. (*Stahl u. Eisen*, 1955, **75**, June 16, 767–769). The author tested 6 emulsion lubricants for cold-rolling strip steel. The ratio (Lubricant) : (Water) was 1 : 20; in some cases soda ash (1 : 400) was added for improving the corrosion protection of the emulsion. The cooling properties of all emulsions were satisfactory, although there were large differences in wetting, residue and slime formation, etc. Those emulsions which have highest wettability and show absence of slime and rust formation are best suited for cold-rolling strip steel.—T. G.

The New Blooming Mill of Böhler and Co. at Kapfenberg. G. Bersa and S. Glavitza. (*Stahl u. Eisen*, 1955, **75**, May 19, 624–629). The new rolling mill consists of a single-stand reversing two-high breaking-down mill, a two-stand reversing mill followed by a single-stand reversing two-high mill. Output is 8000–10,000 tons/month of 1-ton ingots for two-shift operation, with a power consumption of about 90 kW./ton.

Electrical Features of Great Lakes 45 × 90 in. Universal Slabbing Mill. H. C. Hoeft. (*Iron Steel Eng.*, 1955, **32**, Feb., 117–121).

Mechanical Features of Great Lakes 45 × 90 in. Universal Slabbing Mill. P. C. Vetter. (*Iron Steel Eng.*, 1955, **32**, Feb., 112–116).

The Use of Manganese Sulphide for Improving the Hot Rolling of Free-Cutting Low-Carbon Steels. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (5), 957–960). The unfavourable effect of long periods in the soaking pits on the surface quality of high-sulphur steel ingots, due to the low melting point of FeO–FeS inclusions, is discussed. The advantages of the addition of sulphur as MnS are explained, and the results of trials are reported.—T. E. D.

Recent Developments in Heavy Rolling Mill Design. W. Müllenbach. (*Demag News*, 1955, (139), 5–14). An account is given of the design of a number of rolling mills constructed by Demag between 1948 and 1954.—B. G. B.

Swedish Rolling Mills of Recent Design for Intermediate and Small Sections and Wire Products. E. M. Norlindh. (*Stahl u. Eisen*, 1955, **75**, June 2, 700–709).

Opening of the New Section Train at the Hütte Donawitz. W. Graff. (*Maschinenwelt u. Elektrotechnik*, 1955, **10**, May, 133–134).

Heavy Section Rolling Mills: Consideration of their Engineering Aspects. T. Walker. (*West Scotland Iron Steel Inst.: Iron Coal Trades Rev.*, 1955, **170**, Mar. 18, 617–621; *Engineering*, 1955, **179**, Apr. 8, 429–430). The author outlines the principles involved in the layout and design of heavy two-high reversing mills.—G. F.

New Bar and Section Mills at Donawitz, Austria. (*Iron Coal Trades Rev.*, 1955, **170**, May 13, 1115–1116).

Electrical Features of Universal Slabbing and Hot Strip Finishing Mills at Fairless. W. Reid and R. H. Wright. (*Iron Steel Eng.*, 1955, **32**, Jan., 97–104).

Study of the Rolling of Beams in the U.S. A. Petitfrère. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (5), 1007–1020). Roll-pass designs for rolling **I**-beams in the U.S.A. are compared with European designs. The differences are mainly associated with the larger tonnages of product produced in the U.S.A.—T. E. D.

The Use of Radio-Active Isotopes for the Contactless Control of Manufacturing Variables in the Production of Rolled Products. J. Petr. (*Hutnické Listy*, 1955, **10**, (6), 346–352). [In Czech].

MACHINERY FOR IRON AND STEEL PLANT

Recent Progress in the Field of Gas Turbines Applied to Steelworks. Baumann. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, (8), 1617–1639). A gas-turbine cycle burning blast-furnace gas and operating a generator and blower is shown. Operating characteristics are given. Blowing efficiencies of a gas engine operating a piston-blower, an electric turbo-blower, and a gas-turbine-blower are compared. The use of gas-turbine exhaust gas for blast heating is considered and a Cowper recuperation system is suggested. The importance of positioning the gas-turbine close to the blast-furnaces is emphasized.—T. E. D.

The Gas Turbine. Characteristics and Results of Exploitation in Particular in the Steel Industry. Widmer. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, (8), 1593–1616). The one-stage open cycle without and with recuperator and the two-stage cycle are compared. Types of installations are described and illustrated, giving information on operating characteristics.—T. E. D.

Oil-Fired Geared Steam Shunting Locomotive. (*Engineer*, 1955, **199**, May 6, 628–629). The article describes a new Sentinel 0–6–0 steam shunting locomotive: it is of 200 h.p., weighs 50 tons, and has a starting tractive effort of 26,000 lb. The locomotive is oil-fired, has an all-geared transmission, roller-bearing axle-boxes, and steam braking.—M. D. J. B.

Use of Electricity in the Steel Industry. W. F. Cartwright. (*Engineer*, 1955, **200**, July 22, 116–117). This paper reviews the way in which the iron and steel industry affects the national electrical industry now, and how it may affect it in five and ten years' time.—M. D. J. B.

The Organisation of Works Transport. E. R. S. Watkin. (*Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, 22–24). Internal railway traffic is the predominant method of transport in steelworks and it is considered desirable that all railway facilities and employees should be organized by a specialized traffic department.—B. G. B.

The Maintenance of Works Transport. C. E. Roebuck. (*Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, 25–28). The problem of keeping the transport facilities of a steelworks in satisfactory condition is discussed, particular reference being made to Steel, Peech and Tozer, Sheffield.

Road versus Rail Transport. W. F. Cartwright. (*Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, 29–30). Factors affecting the cost of transport in steelworks by rail and road methods are considered. Suggestions are made for obtaining definite conclusions, under steelworks conditions, of the merit of road and rail transport.—B. G. B.

The Relative Merits of Diesel and Steam Traction. A. J. Harby. (*Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, 31–33). Experience obtained by the Steel Company of Wales Ltd. on this problem is described. Conversion to all-diesel traction is considered to have considerable economic and operating advantages.—B. G. B.

Wagons for Bulk Materials. H. R. Mills. (*Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, 34–39). The design of modern British coal and iron ore wagons is compared with those used on the continent and in North America. Factors affecting the design of wagons are considered.—B. G. B.

The Economics of Works Transport. J. H. Turnbull. (*Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, 17–21). The cost of operating steam and diesel locomotives in steelworks is considered in detail. Typical operating costs of works locomotives are examined and divided up into a number of items.—B. G. B.

The Use of Operational Research on British Railways. M. G. Bennett. (*Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, 16).

How to Avoid Traffic Congestion in Works. M. D. J. Brisby. (*Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, 10–15). The application of operational research techniques to the study of congestion of wagons in steelworks is discussed and examples of the results obtained are given.

The Importance of Transport in Iron and Steel Works and Management Efficiency. S. C. Bond. (*Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, 7–9). The organization of the transport department of a steelworks is briefly considered.—B. G. B.

The Relation of the Iron and Steel Industry to British Railways and the Effect of Recent Legislation. M. F. Barnard. (*Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, 3–6). This subject is reviewed, particular emphasis being paid to the relationship between road and rail transport in the U.K.—B. G. B.

Running Properties and Resistance of Travelling Cranes for Various Types of Tread. K. H. Hüser. (*Stahl u. Eisen*, 1955, **75**, Apr. 21, 485–499). Running stability, power uptake, running resistance of a crane, and service life of various types of crane tread and track were studied on one crane in order to obtain results of general validity. Cylindrical flangeless wheels with guide rolls and roller bearings are superior to all other types with respect to running properties and resistance of cranes and wear of tread and track.—T. G.

Modern Combined Box- and Magnet-Type Overhead Travelling Cranes for the Scrap Yard of an Open-Hearth Steel Works. O. Berck and K. H. Hüser. (*Stahl u. Eisen*, 1955, **75**, Apr. 21, 499–502). The authors describe design and construction of

a combined box- and magnet-type overhead travelling crane that hoists 15-ton boxes or 12 tons magnetically for the scrap yard of an O.H. steelworks.—T. G.

Choice of a Branch Line Engine. A. Ogus. (*Usine Nouvelle*, 1955, **11**, May 26, 29–30). An attempt is made to provide theories that can assist in the choice of a shunting engine suitable for a particular use.—T. E. D.

LUBRICANTS AND LUBRICATION

Oil Film Extent in Complete Journal Bearings. J. A. Cole and C. J. Hughes. (*Engineer*, 1955, **199**, Apr. 22, 555–557). This paper reports work carried out at the Mechanical Engineering Research Laboratory on an investigation of temperature distribution and film extent in journal bearings.

Viscosity and Viscosity Changes in Lubrication. G. H. Göttner. (*Stahl u. Eisen*, 1955, **75**, Apr. 21, 502–513). The author discusses the effect of temperature and pressure on the viscosity of lubricants and classifies the lubricants according to their viscosity/temperature (V.T.) behaviour. He then applies the principles to practice and concludes that the indices used to-day do not give a true indication of the behaviour of the lubricant in practical lubrication.—T. G.

Stability of Lubricating Greases in Centralized Lubricating Systems. E. L. Armstrong and C. D. Thayer. (*Iron Steel Eng.*, 1955, **32**, Apr., 84–87). The authors examine the performance of a grease in a centralized lubricating system and come to the conclusion that performance is affected by oil separation, the type of soap, the amount of soap, the viscosity of the mineral oil, and the processing.—M. D. J. B.

Screwdown Lubrication. W. A. Holt. (*Iron Steel Eng.*, 1955, **32**, May, 119–120). The advantages of using lead naphthenate lubricants for screw-down lubrication are described.—M. D. J. B.

The Calculation of the Working Temperature of Plain Bearings. O. Gersdorfer. (*Maschinenbau Wärmewirtschaft*, 1955, **10**, Mar., 69–75; June, 184–188; July, 219–223; Aug., 233–238). The author develops simplified calculations to determine, on the basis of the hydrodynamic lubrication theory, the frictional properties and the heat conductivity of the bearing and lubricant, and hence to establish the working temperature of the bearing. A method is then given for the graphical evaluation of this temperature, using various lubricants. It is shown that additional factors can also be taken into account, and also that the method is not restricted to plain bearings.—L. D. H.

Thermodiffusional Sulphiding of Steels. V. V. Gal'chenko. (*Stanki i Instrument*, 1955, (2), 17–19). [In Russian]. Since iron sulphides in a metal layer have a low valency and large ions, they become strongly electrostatically charged on compression. They thus strongly adsorb lubricants giving a very effective separation of surfaces. Sulphide layers on steel also influence the effect in the contact layer because of the difference between the magnetic properties of ferrous sulphide and steel.—S. K.

Properties and Uses of Pure Molybdenum Disulfide As a Lubricant. A. Sonntag. (*Wire and Wire Prod.*, 1955, **30**, July, 782–786). The origin, structure, physical, and lubricating properties, and applications of molybdenum disulphide are described, and mention is made of favourable results in wire drawing and cold heading.—J. G. W.

The Nature of the Friction Between Solids. F. P. Bowden. (*Advancement Sci.*, 1955, **12**, June, 43–48).

The Function of Lubricants in Metal Working. C. H. Waetjen. (*Schweiz. Arch. Wiss. Techn.*, 1955, **21**, Jan., 20–25). A survey is made of metal-working operations and of the available lubricants. The way in which lubrication operates is described and recommendations are made for the best lubricant for each operation and metal.—J. R. P.

Importance of Lubrication in Cold Rolling. M. Nosek. (*Hutnik*, 1955, **22**, (6), 204–210). [In Polish]. Phenomena taking place on the lubricant/metal boundaries and the importance of the lubricant composition, temperature, and pressure on the process of deformation of metals are discussed.

Molybdenum Disulphide in Lubrication Practice. F. W. Uhlmann. (*Metall*, 1955, **9**, Feb., 88–90). Following a description of the physical properties of molybdenum disulphide, various examples of its application in lubrication practice are quoted, both as a dry lubricant and in suspension or as additive to fluid lubricants.—J. G. W.

Extreme Pressure Lubrication. W. Davey. (*Sci. Lubrication*, 1955, **7**, June, 23–27). The mechanism of extreme pressure lubrication (the most severe case of boundary lubrication) is discussed, with reference to the composition of organo-metal, S and Se, halogen and P compounds, and the use of the lubricants for hypoid gears and metal working. Testing methods and possible developments are described.

Some Aspects of Bearing Lubrication. L. Berner. (*Sci. Lubrication*, 1955, **7**, July, 20–23). Methods and systems for applying grease or oil lubricants to bearings are described. Graphs show permissible intervals for lubrication of ball, roller, or spherical roller bearings.—K. E. J.

Industrial Lubrication Engineering in the U.S.A. G. D. Jordan. (*Sci. Lubrication*, 1955, **7**, July, 12–17, 19). A survey is made of the status and role of the lubrication engineer and the divisional (chief) lubrication engineer in steelworks in the U.S.A. His functions include record maintenance, inspection and testing of lubricants, design of lubrication systems, training junior personnel, and selection and purchase of lubricants.—K. E. J.

Notes on Viscosity as a Property of Lubricating Oils. E. Akester. (*J. S. African Inst. Mech. Eng.*, 1955, **4**, Feb., 237–255). The significance of viscosity is shown in the case of thick film lubrication which is contrasted with boundary lubrication. The nature of viscosity and its measurement in fundamental units are described, leading to the determination of rates of viscous flow and considerations of the hydrodynamic formation of the oil film on cylindrical bearings. The relationship of the ZN/P number to bearing performance is given.—L. E. W.

Latest in Mill Lubrication. (*Steel*, 1955, **136**, May 23, 108, 110). Points of interest are quoted from papers presented to the Association of Iron and Steel Engineers at Detroit. These include the spray application of grease and oil to roll necks, the use of composition bearings and a combination of differential mechanical gearing and variable-speed hydraulic units for continuous mill drives.—D. L. C. P.

WELDING AND FLAME-CUTTING

Welding in an Argon Atmosphere by the Nertal and Nertalic Processes. Present State of Research and Applications. Brillié. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, (6), 1235–1247). The Nertalic process using a current density of 100 A./sq. mm., inverse polarity, and a consumable electrode is described. The examination of the process includes colour photography at 3000 frames/sec. and some stills are reproduced. Inert atmosphere welding with a non-consumable electrode is also discussed with recommendations on welding rod composition. The Nertal process, which uses A.C., is used for aluminium and alloys and for fabrication in thin stainless steel.—T. E. D.

Weldability of Chromium–Molybdenum Steel for High-Pressure and High-Temperature Piping Service. J. Omori. (*Sumitomo Metals*, 1955, **7**, Apr., 83–89). [In Japanese]. Tests were made on 1/0·5%, 2·25/1%, and 5/0·5% Cr–Mo steels. Preheating temperatures of 250–350° C. are suitable. Optimum temperatures for stress relieving are 730–750° C., and for full annealing 860–900° C.—K. E. J.

The Welding Phenomena between Solid and Molten Cast Iron. T. Muraki. (*Waseda Univ., Rep. Castings Res. Lab.*, 1955, (6), 42–48). Conditions of temperature, holding time, etc., were investigated for welding between molten cast iron and steel, in the form of a rod. The molten iron must be kept liquid for a time, so that diffusion across the boundary occurs, before it is allowed to solidify; welding is particularly difficult if the diffusion rate is slow and the solidification rate rapid by comparison.—K. E. J.

Effect of Welding when Superposed upon Prestraining Steel. Y. Ando, I. Yamaguchi, K. Iida, and Y. Imai. (*Rep. Inst. Indust. Sci., Tokyo Univ.*, 1955, **4**, (7), Mar., 283–313). An investigation was made to determine the effect of welding on cold-worked steel. A rimming steel, 13 mm. thick and having a Mn : C ratio $> 2·5$, was stress-relieved at 700° C., cold-worked in degrees up to 10%, and bead-welded under submerged arc. Deleterious effects of pre-straining were not observable in tensile, bending, or fatigue tests, and the corrosion resistance increased after welding. It is concluded that this practice is not harmful.—K. E. J.

The Hydrogen Content in Weld Deposit on Welding. S. Okada, N. Watanabe, and T. Boo. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1953, **4**, Sept., 99–103). [In Japanese]. The H_2 content in the molten metal, arising from water in the electrode coating, may be calculated from the H_2 partial

pressure in the welding atmosphere. To allow for losses of water and organic matter before the coating reaches the arc, corrections based on the water content before and after welding are introduced into the calculation.—K. E. J.

Research on Electric Cutting. C. Matsuda, M. Motoki, and S. Nishimara. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1953, **4**, Sept., 76–82). [In Japanese].

The Special Electric Cutting Process. C. Matsuda, M. Motoki, and S. Nishimura. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1954, **5**, Mar., 49–52). [In Japanese]. A study was made of the electrode-erosion cutting process, for hard metals, etc., wherein a revolving disc in an electrolyte is used as cutting electrode.—K. E. J.

Electric Cutting of Cast Iron and Stainless Steel. C. Matsuda, M. Motoki, and S. Nishimura. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1954, **5**, Mar., 45–48). [In Japanese]. An account is given of work undertaken with a view to improving methods of cutting iron and steel using the oxy-arc (O_2 is introduced through the hollow core of the electrode) and the powder oxy-arc (Fe powder is oxidized in the cutting area with liberation of heat).—K. E. J.

Electric Cutting. C. Matsuda and M. Motoki. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1955, **7**, Mar., 77–80). [In Japanese]. Research was conducted into cutting using an O_2 jet in the arc. A specially-designed electrode gave higher speeds of cutting and lower burn-off velocities. A H.F. high-voltage process gives better surface quality and high cutting speeds.

The Relation between the Water in Electrode Coatings and the Dissolved Hydrogen in Deposit Metal. S. Okada, N. Watanabe, and T. Boo. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1955, **7**, Mar., 127–130). [In Japanese]. The H_2 dissolved in the molten metal during arc welding depends on the water reaching the arc atmosphere. For estimating the dissolved H_2, it was more accurate to calculate from the combined water in the electrode coating than from the total water determined by cold extraction.—K. E. J.

Suppression of Martensite Formation in Flame Cutting. F. Dechner and H. Speich. (*Stahl u. Eisen*, 1955, **75**, July 14, 912–913). Structural steel plates 6–30 mm. thick were flame-cut at 30–36 cm. per min. The cutting burner was followed by a second burner which controlled the cooling of the heat-affected zones to avoid martensite formation. Although controlled cooling of the heat-affected zone by a second burner is far from ideal, hardening of this zone could be successfully prevented. For plates thicker than 30 mm. controlled cooling from one side only was no longer sufficient.

A New Method of Joining Metals. (*Usine Nouvelle*, 1955, **11**, Mar. 10, 29–31; Mar. 17, 31–33). Two types of adhesives for metals have been tested by S.N.C.A.S.O. over several years: (i) rapidly polymerizing adhesives requiring the use of high pressures; (ii) slowly polymerizing adhesives requiring only slight pressure. Particularly severe ageing tests were performed. The two types were found to be of equivalent quality, but the second type is much easier to use. Control and testing are discussed, with particular reference to an ultrasonic method.—T. E. D.

Present Applications of Oxy-Cutting with Iron Powder. (*Usine Nouvelle*, 1955, **11**, June 2, 37–38). In the method, called the Safjet method in France, the iron powder produces a hotter flame and also acts as flux to the oxides of nickel and chromium. As well as being used for stainless steels, for which it was originally developed, it is used for special steels, high-melting steels, cast iron, large lumps of scrap, sheet steel, copper and its alloys, nickel and its alloys, and refractory materials.—T. E. D.

Weldability and Mechanical Properties of two Low-Alloy Steels in the Hardened and Tempered Condition. B. J. Bradstreet. (*Brit. Welding J.*, 1955, **2**, Aug., 347–350). Mechanical tests and controlled thermal severity (C.T.S.) weldability tests have been made on two experimental low-alloy steels, after hardening at 900° C. and tempering at 500°, 550°, 600°, 650° C., in the form of 1½-in. thick plate. Compared with the properties of the steels in the normalized, or normalized and tempered, condition, the room-temperature tensile properties and the impact properties (at test temperatures ranging from − 60° C. to room temperature) have been considerably improved without affecting the resistance to hard-zone cracking.—U. E.

Development and Present Position of Oxyacetylene Welding of Rails. F. Fries. (*Schweissen u. Schneiden*, 1955, **7**, Apr., 144–151; May, 190–198).

Stress-Relieving a Large Welded Pressure Vessel. (*Indust. Gas*, 1955, **18**, Feb., 145–148).

Welding, Brazing, Joining. (*Iron Age*, 1955, **175**, June, L2–L16). Developments and present practices in welding, brazing, and joining are described and future trends predicted.

Automatic Welding Process Uses Carbon Dioxide Gas. (*Iron Steel Eng.*, 1955, **32**, June, 120, 122). This article describes a new automatic welding process which uses low-cost CO_2 for shielding the arc while welding mild and medium-carbon steels.—M. D. J. B.

Automatic Percussion Welding. A. L. Quinlan. (*Trans. Amer. Inst. Elect. Eng.*, 1954, **73**, I, 561–565). This paper describes the development of a machine for the automatic percussion welding of contact blocks to an array of wires projecting from plastic material. Details of design and construction are given.—L. D. H.

Problems of Brazing. J. Colbus. (*Schweisstechn.*, 1955, **9**, Feb., 13–17; Mar., 31–35; Apr., 42–45). A definition is given of brazing, soldering, and bronze-welding. Experiments are described in which silver was cast on to the surface of iron and copper sheet to obtain information on the wetting properties of solders. The effect of flux media on the working temperature is investigated. The effect of tensile strength of the base material on the tensile strength of the joint is discussed, together with the change in metallurgical properties of the joint and the shearing strength.—U. E.

Properties and Weldability of Non-Magnetic Steels. F. Rapatz and A. Schmidt. (*Schweisstechn.*, 1955, **9**, May, 49–55). The mechanical properties and chemical composition of non-magnetic or austenitic steels are discussed and compared with those of iron and alloy steel together with machining properties. It was found that non-magnetic steel can be arc-welded with the same success as an 18/8 steel. A non-magnetic steel can also be joined to an unalloyed steel by welding. Hard facing and powder cutting did not affect the mechanical properties of non-magnetic steel adversely.—U. E.

Fundamentals and Requirements of Oxyacetylene Stress Relief Treatment. H. G. Kunz. (*Schweissen u. Schneiden*, 1955, **7**, July, 291–300). The effect of a heat-treatment, carried out with the help of oxy-acetylene burners, on the mechanical properties of welded construction is discussed.

Progress in Welding and Cutting. The Effect of Hydrogen on Weld Quality. K. L. Zeyen. (*Schweissen u. Schneiden*, 1955, **7**, May, 200–207; July, 305–313). A review is given of published data on the effect of hydrogen in weld metal and base metal on the quality of the weld. Special attention is drawn to the known phenomenon of "fish eyes."—U. E.

Advantages of Welding in Design and Fabrication. C. Stieler. (*Schweissen u. Schneiden*, 1955, **7**, June, 274–279). A review is given of the improvements in welding of structural steels. Welding is compared with riveting, and examples are given of savings in steel when applying welding to the construction of bridges, railway wagons, and other structures.

Is the Oxyacetylene Stress-Relief Treatment Necessary? W. Soete. (*Schweissen u. Schneiden*, 1955, **7**, July, 300–305). The effect of initial stresses on deformation, brittle fracture of steel, fatigue properties, and corrosion of welded structure, and the useful application of the oxy-acetylene stress-relief treatment are discussed.—U. E.

Problem of the Reduction of Residual Stresses arising in Building Up by Welding. H. Bühler. (*Z.V.d.I.*, 1955, **97**, Jan. 21, 80–84). The efficacy of three different methods of reducing residual stresses having their origin in the building up of defective bolts by welding was investigated, the methods being plastic deformation of built-up layer by drawing through a die; plastic deformation in compression of entire cross-section of the bolt; removal of core material before and after welding. Stresses were substantially smaller in bolts which had been bored out longitudinally before welding.—J. G. W.

A Simple Procedure for Ascertaining Heat Time in Spot Welding. A. Gaubert and U. Riedinger. (*Sondage Techn. Connexes*, 1955, **9**, May-June, 147–149). The welding electrodes are connected through a transformer to an electrode of 18/8 stainless steel, supporting a sheet of paper impregnated with potassium ferrocyanide and ammonium nitrate solution, and a 60/40 brass electrode resting on the paper. A trace is obtained on the impregnated paper as the spot-welding machine operates.—T. E. D.

Quality Control of Radiographic Pictures in Weld Inspection.

C. Brachet. (*Sondage Techn. Connexes*, 1955, **9**, May-June, 131–140).

A Process for Killing the Molten Pool in the Welding of Steels. A. Leroy, H. Granjon, and M. Evrard. (*Sondage Techn. Connexes*, 1955, **9**, May-June, 127–129). The reaction between carbon and oxygen in the course of welding leads to effervescence, and hence to porosity of the weld. This can be avoided by the addition of aluminium, silicon, or ferro-silicon, or by metallization of the edges to be welded by painting with an aluminium paint.—T. E. D.

Development of the Use of a Gaseous Flux in the Joining of Metals. B. Liebesman. (*Sondage Techn. Connexes*, 1955, **9**, May-June, 119–126). Some details of the use of a gaseous flux for welding, brazing, and weld-brazing are given. The apparatus for introducing the flux into the flame is briefly described. A protective film of boric anhydride is deposited on the heated surface.—T. E. D.

Time Development of Weld Defects on Penstocks. H. Borot. (*Sondage Techn. Connexes*, 1955, **9**, May-June, 153–155). Tests were performed on welded high-pressure pipes of Cu–Cr steel to simulate, as far as possible, working conditions and incidental handling.—T. E. D.

The Welding of Faults in Thin-walled Iron Castings. I. G. Sajenko. (*Giessereitechnik*, 1955, **1**, May, 76–77; *Engineering News*, 1954, **34**, 81–83). A method of welding thin-walled castings by oxy-acetylene methods using thermostats to maintain the temperature of the part being repaired, as well as cast-iron rods as additives, is described and illustrated.

The Production of Continuous Rail-lengths by Flash Butt Welding. (*Machinery*, 1955, **86**, June 3, 1188–1194).

Two Performance Tests Select the Best Welding Electrodes. K. Rose. (*Mat. Methods*, 1954, **40**, Dec., 136–138). Electrode test procedures developed by the Ford Motor Co. are described. The testing equipment provides controlled variable welding speed, electrode pressure, and welding current. Different test conditions are used to evaluate electrodes for frame and 20-gauge sheet welding.—P. M. C.

Brazing Titanium to Titanium and to Steels. D. Brooks. (*Metal Treatment and Drop Forging*, 1954, **21**, Dec., 583–585). This is a review of American work undertaken to evaluate commercially available alloys and to develop new alloys for use in joining titanium to titanium, to mild steel, and to stainless steel. Successful brazing is reported with several alloys, all of which contain silver together with varying amounts of Cu, Zn, Cd, Mn, and Sn.—P. M. C.

MACHINING AND MACHINABILITY

The Activities of the Machine Tool Experimental Station (S.E.M.O.). Champetier and Janvier. (*Usine Nouvelle*, Special No., Spring, 1955, 61–67). The investigations include a study of power requirements as a function of cutting speed. Machine tool vibrations during turning have also been investigated. The design of dynamometers incorporated in tool carriers, in which provision is made for air cooling, is shown. The technique can be applied to milling and drilling. Measurement of torque and force on a drill is also discussed, and the required strain-gauge bridge circuit is given.—T. E. D.

Spark Machining. (*Usine Nouvelle*, Special No., Spring, 1955, 173–183). The principles of spark machining and methods used in its application to the machining of hard materials are outlined. The effects of voltage, frequency, electrode material, and the liquid under which the arc is maintained are discussed.—T. E. D.

Magnetic Particle, Penetrant and Related Inspection Methods As Production Tools for Process Control. H. Miger. (*Steel Processing*, 1955, **41**, Feb., 86–91, 127).

A Modern Perspective of the Grinding Process. H. R. Letner. (*Steel Processing*, 1954, **40**, Dec., 774–779, 798). Theories of chip formation are reviewed for cutting tools of simple geometry, the results being of interest in connection with the action of abrasives. The mechanism of grinding with abrasive wheels is then discussed, and mechanical and thermal effects on the ground surface are dealt with.—P. M. C.

Russian Work on Sulphided Steels. W. G. Cass. (*Iron Steel*, 1955, **28**, May 11, 204, 263, 288). The author summarizes recently published Russian work dealing with the wear resistance of sulphided steels and with the thermo-diffusion process of sulphiding.—G. F.

Residual Stresses Caused by Blunt Cutting Tools. H. Bühler and W. Schepp. (*Z.V.d.I.*, 1955, **97**, June 21, 548–551). The residual stresses caused by the use of worn boring tools used in machining heat-treated steel and brass were measured and the results contrasted with almost stress-free conditions observed when using sharp tools.—J. G. W.

Spark Machining. D. W. Rudorff. (*Mét. Constr. Mécan.*, 1955, **87**, June, 489–498). The principle of this method of machining, which is of use for very hard metals, is explained and examples of its practical use are given.—B. G. B.

On the Drilling of Metals. I. Basic Mechanics of the Process. C. J. Oxford, jun. (*Trans. Amer. Soc. Mech. Eng.*, 1955, **77**, Feb., 103–114). The complex cutting action of a twist drill has been investigated by the use of a quick stop technique used to ' freeze ' the action. By this method relative motion between drill and workpiece is suddenly prevented by rapidly accelerating the workpiece up to the speed of the drill. The formation of chips both along the cutting edge and under the chisel edge can then be carefully examined.—D. H.

The Shear Stress in Metal Cutting. M. C. Shaw and I. Finnie. (*Trans. Amer. Soc. Mech. Eng.*, 1955, **77**, Feb., 115–125). The factors which could influence the flow stress in metal cutting are considered in an attempt to determine the reason for the discrepancy between metal-cutting stress/strain data and similar data from other materials tests, particularly torsion.—D. H.

Some Practical Aspects of Spark Machining. (*Machine Shop Mag.*, 1955, **16**, Apr., 201–207).

Some Aspects of the Machining of Bright Drawn Mild Steels. A. W. F. Comley. (*Machine Shop Mag.*, 1955, **16**, May, 286–289).

The Production of Perforated Metal Sheet. (*Machinery*, 1955, **86**, Apr. 15, 792–803).

Applications of Sub-Zero Cooling in Metal-Working Operations. (*Machinery*, 1955, **87**, July 22, 195–196). Refrigeration of metal components for assembly purposes are discussed, and a table showing the expected contraction for various metals when cooled to sub-zero temperatures is given.

Types of Steel, Microstructure, Chemical Composition, Tool Compatibility—How They Affect Machinability. (*S.A.E.J.*, 1954, **62**, Sept., 47–53). This article highlights some of the information given in the report " Machinability of Ordnance Steels " by Division XI of the SAE Iron and Steel Technical Committee. The broad general principles of machinability, based on fundamental properties such as strength, hardness, ductility, and microstructure are outlined, and can be used as the basis for selecting steels with the most favourable machinability consistent with the specifications of the end product.—P. M. C.

Machining and Machinability. F. W. Boulger. (*Canad. Metals*, 1955, **18**, Mar., 40–44; Apr., 52–56). The author considers that machinability is controlled by the frictional properties of a metal and its strength in the actual cutting operation. The results obtained by a simple test measuring the thrust on the tool and the resultant feed show that the thrust force is equal to a constant $\times \sqrt{\text{feed}}$. The constant varies for different materials and is highest for a steel which is difficult to machine.—B. G. B.

Ultrasonic Tools for Hard-to-Machine Materials. J. P. Aloisio and N. Clark. (*J. Inst. Prod. Eng.*, 1955, **34**, May, 315–320).

Electroforming in Electronic Engineering. P. M. Walker, N. E. Bentley, and L. E. Hall. (*Trans. Inst. Metal Finishing*, 1955, **32**, Advance Copy No. 11). The authors describe the production of hollow components by electroforming. Details are given of the preparation of the stainless-steel mandrels and of stress measurements in electrodeposits using a form of spiral contractometer.—A. D. H.

Rolling Shaft Journals instead of Polishing. A. M. Asnes, B. I. Grebenchuk, and V. P. Vlasov. (*Stanki i Instrument*, 1954, (12), 26–27). [In Russian]. The effect of rolling on the quality of steel surfaces and the application of the technique to the finishing of shaft journals are described.—S. K.

CLEANING AND PICKLING

Suggested Guide to Laboratory Metal Cleaning. J. C. Harris, W. Stericker, and S. Spring. (*Amer. Soc. Test. Mat. Bull.*, 1955, Feb., 31–34).

The Surface Preparation of Ferrous Metals. J. Liger. (*Mét. Constr. Mécan.*, 1954, **86**, Oct., 763–769; 1955, **87**, Feb., 119–122). The removal of scale, oxide films (produced during heat-treatment), rust, slag, and oil and grease from steel surfaces is considered. The importance and prevention of surface defects are discussed together with the formation of

the Beilby layer during polishing. The use of wet-sand blasting and shot peening are described and the selection of a particular method for cleaning large and small surfaces is explained.—B. G. B.

How to Select Abrasives for Blast Cleaning. V. F. Stine. (*Precision Met. Mold.*, 1955, **13**, Jan., 55–56, 82).

More Production through Chemical Maintenance. A. D. Nesbitt. (*Iron Steel Eng.*, 1955, **32**, June, 104–112). This paper discusses the problems attendant on cleaning metal equipment and refractory masses. The use of chemical solvents for cleaning blast-furnace cooling systems, boilers, O.H. cooling systems, coke-plant gas scrubbers, condensers, etc., is described.—M. D. J. B.

Cleaning by Hydraulic Sand-Blasting. L. P. Solov'ev. (*Liteĭnoe Proizvodstvo*, 1955, (3), 10–13). [In Russian]. Investigations carried out with a special experimental installation for supplying jets of high-pressure sand-containing water are described. The jets were allowed to impinge on a series of steel plates, the resulting loss in weight of these being used to estimate the effectiveness of the particular arrangement, nozzle wear also being determined. The cleaning of steel, iron, and non-ferrous castings, and of sheet steel 20 and 10 mm. thick, by hydraulic sand-blasting was studied. Comparison with dry sand-blasting showed that the productivity of the hydraulic method was 4·6–5·8 times higher.

Correct Abrasive Selection in Blast Cleaning Metals. V. F. Stine. (*Steel Processing*, 1955, **41**, Feb., 100–103). The very wide range of commercially used abrasives, ranging from silicon carbide to ground corncobs, is tabulated, and the applications, types of blasting equipment, and effect of particle shape and size are described.—P. M. C.

Barrel Finishing. H. B. Underhill. (*Canad. Metals*, 1955, **18**, June, 54–57).

Proper Handling Devices Aid Batch Pickling. W. A. Risher. (*Iron Age*, 1955, **175**, May 12, 95–97).

PROTECTIVE COATINGS

Protection Against Corrosion by Metallic Coatings. P. Morisset. (*Usine Nouvelle*, Special No., Spring, 1955, 85–101). Methods of coating are discussed including hot dipping, metal spraying, electroplating, chemical depositing, cladding, and welding. Surface treatment, chemically, electro-chemically, or thermo-chemically, is included. Corrosion mechanisms and the effect of coating structures are examined. The influence of joint design and sheet thickness are mentioned. Performances of coatings are tabulated and recommendations are made.—T. E. D.

Apparatus V-166 for Controlling Coating Thickness. S. A. Vinokurskii and S. V. Sobolevskii. (*Stanki i Instrument*, 1955, (1), 25). [In Russian]. The thickness of antimagnetic and semi-magnetic coatings is found by measuring the force required to remove a permanent magnet from contact with the coated surface.—S. K.

The Prevention of the Occurrence of Poisonous Waste Water in Electrolytic Plants by Means of the Lancy Process. R. Springer. (*Metalloberfläche*, 1955, **9**, May, B65–B69). The application of the Lancy process to the treatment of poisonous waste water from copper- and chromium-plating baths is described.—L. D. H.

The Treatment of Waste Waters from Electroplating Operations. G. Rupprecht. (*Metalloberfläche*, 1955, **9**, May, B70–B73).

High-Output Plating Machine Incorporates Job Shop Flexibility. A. D'Agostino. (*Iron Age*, 1955, **175**, June 9, 75–77). A new fully automatic Ni–Cr plating machine with 20 tanks, at present plating furniture components at a high rate, is described.—D. L. C. P.

Metal Finishing. (*Iron Age*, 1955, **175**, June, G2–G16). Past, present, and future trends in plating, dipping, painting, coating, and enamelling are reviewed.—D. L. C. P.

Dual Disposal System Fully Neutralizes Plating Wastes. W. G. Patton. (*Iron Age*, 1955, **175**, May 5, 102–104). A plant is described for continuously treating wastes from acid, alkali, and cyanide plating and metal-stripping operations, to allow their disposal. The cyanides are converted to cyanates with chlorine. Acids are neutralized for rejection to the sewers.

Automatic Plating Installation with Provision for Cell Selection. T. J. Doyle. (*Machinery*, 1955, **86**, June 10, 1279–1286). A completely automatic machine built by the Udylite Corp., Detroit, U.S.A. for plating complicated motor-car bumpers at a high production rate is described.—M. A. K.

Heat Treating and Plating Shop Layout. (*Metalworking Prod.*, 1955, **99**, May 27, 933–944). The article describes a new plating and heat-treatment shop at the Endicott works of International Business Machines Corp., U.S.A. Processes and equipment have been selected for cleanliness, safety of control, and minimum handling.—M. A. K.

Brush Plating Now Practical. M. Rubinstein. (*Mat. Methods*, 1954, **40**, Dec., 98–101). The French 'Dalic' process, whereby selective electroplating of all the usual metals is accomplished by using an anodic swab, is described. The main characteristics of the process are listed and various applications described.

Considerations on the Electroplating of Alloys. R. Piontelli. (*Met. Ital.*, 1955, **47**, May, 204–209). [In Italian]. The author examines the nature of alloys suitable for electroplating. He considers both the thermodynamic and kinetic properties of these alloys, the theoretical mechanism of the phenomenon and finally the practical applications, particularly of tin alloys.—M. D. J. B.

Some Comments on the Question of the Condition and Treatment of Metal Surfaces. H. Wiegand. (*Metalloberfläche*, 1955, **9**, Apr., A50–A53). The following subjects are surveyed briefly, and outstanding problems are indicated: hot-dip galvanizing, 'wettability' of metal surfaces, diffusion, passivity, and other surface phenomena.—L. D. H.

The Evaluation of Electrolytic High-Output Baths. R. Weiner. (*Metalloberfläche*, 1955, **9**, Apr., B49–B52).

Equipment for Electrodeposition. A. Lamarca. (*Corrosion et Anti-Corrosion*, 1954, **2**, Nov.-Dec., 281–286; 1955, **3**, Jan.-Feb., 38–44). General principles are discussed, and the section on plant for surface preparation covers descaling, polishing, and degreasing equipment. Electroplating plant for the plating of mounted items and also for plating in bulk are surveyed.—T. E. D.

Tentative Standard Method for Measuring Electrical Conductance of Coating on Buried Pipe Lines. (*Corrosion*, 1955, **11**, Feb., 59–62). N.A.C.E. Technical Unit Committee T–2D on Standardization of Procedures for Measuring Pipe Coating Conductance.

A New Method of Analysing the Stresses and Strains in Deposited Coatings. H. J. Pick. (*Trans. Inst. Metal Finishing*, 1955, **32**, Advance Copy No. 3). A formula is derived to determine the 'linear free strain'—that strain which a deposited coating would undergo in a direction parallel to the base if it were deposited on an infinitely thin base of no mechanical strength.—A. D. H.

Crack Free Chromium Plating Process. (*Mech. Eng.*, 1955, **77**, June, 516–517). Brief details are given of a new electroplating process developed by United Chromium Inc., U.S.A., for the deposition of crack-free corrosion-resistant chromium plate directly on to a steel surface without copper and nickel undercoating.—D. H.

The Protection of Metals by the Coalescence of Polyethylene or Polyamide Powders. M. G. Friard. (*Corrosion et Anti-Corrosion*, 1955, **3**, May-June, 137–142). Polyethylene and polyamide (Rilsan) powders can be consolidated on the metal surface by a number of methods, which, with the exception of flame projection, are briefly described. A number of precautions to be observed, when using plastic coatings, are discussed.—T. E. D.

Service Life of Tools and Wearing Parts Increased by the Phosphate Process. H. Bethge. (*Metallurgie*, 1955, **5**, May, 161–163).

Effect of the Structure and Composition of Iron on Enamel Quality. I. N. Yukalov. (*Liteĭnoe Proizvodstvo*, 1955, (2), 1–5). [In Russian]. To establish the technology for obtaining high-quality enamel surfaces on cast-iron chemical apparatus, the effect on such surfaces of the structure, composition, and production technique of cast iron were investigated. At the same time causes leading to the formation of the main types of surface defects were elucidated. The results of the investigation are applicable to all types of relatively thin-walled cast-iron apparatus.—S. K.

High Temperature Ceramic Coating for Jet Engines Replaces Critical Alloys. J. V. Long. (*Western Metals*, 1953, **11**, July, 54–56). The development of ceramic coatings for application to low-alloy and stainless-steel components by the Solar Aircraft Co., California, is outlined.—P. M. C.

Montag Enameling Methods Aid in Cutting Costs. H. E. Jackson. (*Western Metals*, 1953, **11**, Jan., 48–50). The vitreous enamelling procedures at the Montag Co., Portland, U.S.A. are described and illustrated.—P. M. C.

The Resistance Strain Gauge as a Means of Determining the Elastic Constants of Ceramic Materials. R. W. Batchelor. (*Trans. Brit. Ceram. Soc.*, 1955, **54**, Jan., 40–58). The principles of the resistance strain gauge are outlined and the precautions necessary to obtain accurate measurements are stressed.—D. L. C. P.

Further Study of Sintering Phenomena. D. R. Wilder and E. S. Fitzsimmons. (*J. Amer. Ceram. Soc.*, 1955, **38**, Feb., 66–71). An investigation is reported into the factors influencing the sintering behaviour of ceramic materials, particularly aluminium oxide. The rate and degree of sintering increased with decreasing particle size; loose powders exhibited sintering phenomena when the particle size was small.—D. L. C. P.

Apparatus for Automatically Recording Strains Between Enamel and Metal. J. D. Walton. (*J. Amer. Ceram. Soc.*, 1955, **38**, Mar., 114–118).

Sintering of Refractory Powders. P. Schwarzkopf. (*Bull. Amer. Ceram. Soc.*, 1955, **34**, Feb., 45–47). The sintering of carbides, nitrides, borides, and silicides is discussed; theories of metallic sintering are generally applicable.—D. L. C. P.

A New Technique for Simultaneous Recording of Strains and Temperature in Enamel–Metal Systems. J. H. Lauchner, R. L. Cook, and A. S. Andrews. (*Bull. Amer. Ceram. Soc.*, 1955, **34**, Apr., 105–108). The test involves heating an enamelled strip in a furnace. A photoelectric cell is arranged to measure the deflection of the specimen, and temperature is measured by thermocouple.—D. L. C. P.

Evaluation of a Short Column Water Elutriator. D. R. Wilder and E. S. Fitzsimmons. (*Bull. Amer. Ceram. Soc.*, 1955, **34**, Apr., 109–114). The elutriator described was used for separating sub-sieve fractions, and particle size determinations.—D. L. C. P.

Metal Ceramic Interactions: V. Note on Reactions of Metals with Titanium Carbide and Titanium Nitride. W. D. Kingery and F. A. Halden. (*Bull. Amer. Ceram. Soc.*, 1955, **34**, Apr., 117–119). Reactions at interfaces and in powder mixtures of titanium nitride and titanium carbide with iron, nickel, molybdenum, silicon, niobium, titanium, and zirconium were investigated at 1600° and 1800° C. Extensive solution and solid-solution formation was observed.—D. L. C. P.

Insurance for High Temperature Coatings. E. S. Barnhart. (*Steel*, 1955, **136**, Apr. 11, 130–131). The process control system for ceramic coatings at Solar Aircraft Co., Calif., is described; allowable defects and repairs are specified.

Migration of Cobalt during Firing of Ground-Coat Enamels on Iron. W. N. Harrison, J. C. Richmond, J. W. Pitts, and S. G. Benner. (*Inst. Vitreous Enamellers Bull.*, 1955, **5**, May, 121–134). Cobalt 60 was incorporated in a porcelain enamel ground-coat and applied to enamelling-iron blanks. Under normal firing conditions a metallic layer $\sim 0{\cdot}01\ \mu$ thick is formed at the enamel/metal interface. The cobalt-rich phase penetrates into the metal only on prolonged heating at 1300° F.—A. D. H.

Electrostatic Paint Spray for Automatic Finishing. I. Feldman. (*Precision Met. Mold.*, 1955, **13**, June, 63–66). Details are given of a new finishing system installed at the works of Swingline Speed Products Co., U.S.A., and designed to handle steel stampings or zinc-base die castings interchangeably.

POWDER METALLURGY

Modern Processes for the Production of Hard Alloys. R. Bernard. (*Met. Ital.*, 1955, **47**, June, 245–250). [In French]. After a brief historical introduction, the author describes the manufacture of the basic product alloy, i.e. the 94% tungsten carbide and 6% cobalt alloy. The development of the wide range of modern alloys is discussed with particular reference to abrasion and shock resisting alloys.—M. D. J. B.

Development Trends in Powder Metallurgy. A. Fransson. (*Tekn. Tidskr.*, 1955, **85**, Apr. 12, 325–331). [In Swedish]. The author describes methods of overcoming the initial properties of powdered metals so as to secure dense or porous alloys and goes on to discuss the mechanical properties and applications of Al, Be, Ti, Zr, and Mo. The prospects for ceramic metals containing oxides, carbides, or borides are reviewed.—G. G. K.

Deposition of Hard-Facing Alloys in Powder Form. (*Engineering*, 1955, **179**, June 17, 773–774). This article describes a process for the deposition in powder form of hard-facing alloys possessing heat, wear, and corrosion resisting properties.

Behaviour of Fibrous and Powder Materials under Intense Electrostatic Fields. C. Matsuda and M. Motoki. (*Kyoto Univ., Eng. Res. Inst. Tech. Rep.*, 1951, **1**, (3), Mar., 28–51). The behaviour of powders, of varying sizes, of marble, carborundum, coal, ores of Mn, Co, and Fe, Fe powders, etc., were investigated, using symmetrical and unsymmetrical electrodes, and applied voltages of the order of 4–16 kV. A process for electrostatic separation of such powders was devised, using sphere-to-plane electrodes. In D.C. fields the sparking voltage and voltage gradient are considerably reduced by the presence of powders in the field.—K. E. J.

Progress Made in Powder Metallurgy in 1953. W. Scholz. (*Stahl u. Eisen*, 1955, **75**, June 30, 856–861).

PROPERTIES AND TESTS

Experimental Studies on Internal Friction in Solids. T. Nishihara and H. Miki. (*Kyoto Univ., Eng. Res. Inst. Tech. Rep.*, 1951, **1**, (1), Mar., 1–18). Logarithmic decrements were measured for transverse vibration over a wide frequency range in brass and cold-drawn water-quenched C steel after low-temperature annealing. Observed values do not agree with those predicted from the thermo-elastic theory, but the discrepancy can be corrected by introducing a term for decrement due to solid friction. Internal strain can be clarified by constants related to the retardation and amount of decrement attributed to internal solid friction.—K. E. J.

Deep-Drawing Steels. H. Hoff. (*Stahl u. Eisen*, 1955, **75**, July 28, 949–958). The author enumerates the various requirements of deep-drawing steels such as chemical analysis, structure, surface quality, etc. He deals with the properties of rimming, semi-killed, and killed steels and gives recommended analyses for high-quality deep-drawing steel and the mechanical properties necessary. Hot and cold rolling of strip and sheet and their effect on structure and texture are discussed. The paper ends with consideration of the occurrence of stretcher strains and their prevention.—T. G.

Relaxation Tests on Metals at High Temperatures. A. A. Chitkov. (*Hutnické Listy*, 1955, **10**, (8), 450–455). [In Czech].

Use of Radioactive Isotopes for Controlling the Homogeneity of Solids and Determination of Linear Dimensions. M. B. Neĭman. (*Stanki i Instrument*, 1955, (4), 1–5). [In Russian]. A number of devices and techniques based on the use of radio-active isotopes are described and critically considered. For control of homogeneity and detection of internal defects, measurement of the difference in transmission of two beams of radiation from a common source is recommended. For wall-thickness determination, reflection and absorption techniques are satisfactory and examples of the industrial automatic control application of the latter are given. A section is included on the sensitivity and accuracy of apparatus for contactless thickness determination.—S. K.

An Experimental Study of the Change in Young's Modulus of Quenched Carbon Steel due to Wetting by Liquids. M. Sato. (*J. Sci. Res. Inst.*, 1955, **49**, Mar., 1–3). Young's modulus is lowered by liquids such as methanol, paraffin oil, toluene, glycerine, and distilled water, but raised by kerosene, spindle oil, and soya-bean oil. The lowering effect is proportional to the surface tension of the liquid, and is attributed to surface-energy effects; results are in agreement with those of Benedicks and Härédn (*Ark. Fys.*, 1951, **3**, 407).—K. E. J.

Dimensional Changes due to Annealing of Plastically Cold-Worked Metals. I. Length-change due to Annealing of Plastically Elongated Low Carbon Steel Bar. II. Changes in Length and Diameter due to Annealing of Low Carbon Steel Bars Plastically Elongated or Compressed. H. Sekiguchi and M. Inagaki. (*Nippon Kinzoku Gakkai-Si*, 1955, **19**, Jan., 24–27; 28–31). [In Japanese]. Results are given for the change in length of low-C steel bars annealed after elongation, and the influences of the following factors are identified: degree of working, annealing temperature, annealing time, and annealing above the transformation temperature. When comparisons were made between bars plastically elongated or compressed at room temperature, it was found that low-temperature annealing produces dimensional changes in the same direction as the deformation due to working; annealing at temperatures above the A_1 point always produces a decrease in length and increase in diameter.—K. E. J.

Plastic Strain and Stress Relations at High Temperatures. A. E. Johnson, N. E. Frost, and J. Henderson. (*Engineer*, 1955, **199**, Mar. 18, 366–369; Mar. 25, 403–405; Apr. 1, 457–458). The work described in this paper is part of a general research into the short-time combined stress properties of metallic alloys. It comprises tests made to determine the

plastic-strain/stress relations for a 0·17% C steel at 350° and 450° C. and an RR 59 aluminium alloy at 20°, 150°, and 200° C., under both simple and general complex stress-loading conditions.—M. D. J. B.

The Complete Elasticity Law for Some Metals According to Poynting's Observations. M. Reiner. (*Appl. Sci. Res.*, 1955, **5**, Section A, 281–295). It is shown that Reiner's general equation of an isotropic elastic material is confirmed by Poynting's results on metal wires.—B. G. B.

Strain Gauge by Resistance Strip. II. T. Nishihara, H. Miki, and G. Naito. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1953, **4**, Sept., 20–23). [In Japanese]. Methods of reducing variations in the gauge factor and resistance of the new device include use of carbon black of preferred particle size and shape.

Strain Gauge by Resistance Strip. III. T. Nishihara, H. Miki, and G. Naito. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1954, **5**, Mar., 21–24). [In Japanese]. Details are given of the determination of the characteristics of the device, the factor of which can be stabilized within $\pm$ 3%. An account is given of its use to determine residual stresses in bored holes.—K. E. J.

Stress Equations for Strain Gage Rosettes. C. C. Perry and H. R. Lissner. (*Product Eng.*, 1955, **26**, July, 207–211). For different types of rosette, using from two to four gauges, a table has been prepared showing the major stresses in terms of the measured strains.—E. A. C.

The Effect of Prestraining in Simple Tension and Biaxial Tension on Flow and Fracture Behaviour of a Low Carbon Deep-drawing Steel Sheet. F. Garofalo and J. R. Low, jun. (*J. Mech. Phys. Solids*, 1955, **3**, July, 275–294). Fully-killed deep-drawing steel sheet was stretched in the direction of rolling or bulged in a circular or eliptical tester; its subsequent properties as revealed in the tensile test were measured at various angles to the rolling direction. The effects of this pre-strain on the yield stress, rate of work-hardening, uniform elongation, and mechanical anisotropy are analysed and related to theory.—J. G. W.

Simple Tensile Tests of Standard Sections in A 37 Steel. F. Hebrant and L. Demol. (*Acier, Stahl, Steel*, 1955, **20**, Apr., 173–177). This paper compares the values obtained for elastic limit and ultimate strength when determined by tests on classic test pieces and when determined by tests carried out on rolled sections.—M. D. J. B.

Tensile Tests on Rivetted Assemblies on A 37 Steel. F. Hebrant and L. Demol. (*Acier, Stahl, Steel*, 1955, **20**, Apr., 178–184). Details are given of tests carried out on 95 riveted assemblies. The effects of slip and plastic behaviour are discussed.—M. D. J. B.

Tests on Stanchions Bent in Single Curvature about Both Principal Axes. J. W. Roderick. (*Brit. Welding J.*, 1955, **2**, May, 217–224). In continuation of the series of investigations into the behaviour of stanchions in the plastic range, tests have been performed on stanchions connected to beams about both principal axes. The beams remained elastic throughout the tests and various combinations of loading were investigated. As compared with stanchions connected to beams about the minor axis only, loads on the major-axis beams caused considerable decrease in yield load, but little decrease in collapse load. A series of tests in which the minor-axis beams remained unloaded showed that the stiffness had a great influence on the collapse load of the stanchion, but almost no influence on the yield load.—U. E.

Longitudinal Impact Tests of Long Bars with a Slingshot Machine. W. Ramberg and L. K. Irwin. (*Amer. Soc. Test. Mat.*, Preprint, 1955, No. 93A). A slingshot machine for making impact tests at the National Bureau of Standards is described. Results of tests carried out on steel and copper bars are discussed. Strain pulses in steel were attenuated with much less change in shape than predicted by the simple von Karmán theory of plastic strain waves.—B. G. B.

The Impact Tube: A New Experimental Technique for Applying Impulse Loads. G. Gerard. (*Amer. Soc. Test. Mat.*, Preprint, 1955, No. 93C). By rupturing a diaphragm which separates a high- and a low-pressure chamber an expansion wave is created which travels toward the opposite wall of the high-pressure chamber containing the specimen under investigation.—B. G. B.

Reproducibility of Charpy Impact Test. D. E. Driscoll. (*Amer. Soc. Test. Mat.*, Preprint, 1955, No. 93D). A special heat of steel was cut up into 18,000 blanks and heat treated to 3 energy levels; 200 specimens at each energy level were tested in Charpy machines manufactured by two different companies to obtain the deviation and average energy values. The remainder of the specimens are being used to check Charpy impact machines throughout America to determine the causes of the variations encountered.—B. G. B.

The Principal Errors of Notched-bar Impact-test Hammers. W. Förster. (*Met. u. Giesserei Techn.*, 1951, **1**, Feb., 45–47). Experiments and theoretical calculations have shown that the impact values obtained with various types of pendulums differ according to the design of the mechanism.—L. J. L.

Rare Earths Improve Impact Properties of 4330. H. Schwartzbart and J. P. Sheehan. (*Iron Age*, 1955, **175**, May 26, 103–106). Figures are given showing the effect of mischmetall additions on the properties of hardened and tempered steel. The rare earths improve the transverse impact properties without affecting hardness. Although the product is costly it may be valuable for parts requiring optimum mechanical properties.—D. L. C. P.

International Standardization of Impact Test-Pieces. Comparative Study of Results obtained with Mésnager, Charpy and Charpy-Izod Tests. M. Signora and F. Cappelli. (*Met. Ital.*, 1955, **47**, Apr., 145–160). [In Italian]. The authors give a detailed account of tests carried out on Mésnager, Charpy, and Charpy with Izod notch test pieces for a range of carbon steels. It has been possible to determine the range of tenacities shown by the different steels and also to measure the degree of selectivity of the test piece itself. Although international agreements specify the Charpy test, results indicate that the Charpy test piece with Izod notch is preferable.—M. D. J. B.

The Difference in Work-Hardening in Flat-Rolling and Drawing of Wire. W. Lueg and K. H. Treptow. (*Stahl u. Eisen*, 1955, **75**, June 16, 757–767). The authors studied the difference in work-hardening of eight carbon steels containing 0·03–1% carbon during flat-rolling and wire-drawing. Total reduction in area of both types of working was similar (97·5%). The results are presented in graphs for total reduction and for the reductions of individual passes which were varied. Work-hardening of rolled wire was lower than that of the drawn wire with the exception of the steel with the lowest carbon content and of all other steels for low degrees of working.—T. G.

Viewpoints on the Linde Method of Stress Relieving. R. Gunnert. (*Brit. Welding J.*, 1955, **2**, May, 200–204). The paper comments on the Linde method of low-temperature stress-relieving and its effectiveness in relieving residual welding stresses. It is claimed that in restrained plates both longitudinal and transverse residual stresses approach the yield point of the material. From theoretical considerations it is considered that the Linde method of stress-relief cannot provide much reduction in these stresses without causing brittleness.—U. E.

Residual Stress-Release by Local Heating. K. Iwase, T. Sano, and M. Kyotani. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Dec., 639–643; 644–648). [In Japanese]. Laboratory tests on steel and 40/60 brass showed that residual mechanical, welding or other stress can be diminished by heating a portion only of the specimen to a temperature at which recrystallization occurs; the treatment is most effective if applied at positions where stress is high and the inclination of the stress distribution curve steep. In a low-C steel plate, 3 mm. thick, electrically welded, satisfactory results were obtained by heating three portions to 650° C. individually; the effect at 1000° C. was more pronounced.—K. E. J.

Results of Stabilization Treatments on Mechanical Properties of Iron Coatings. (*Fonderie*, 1955, Mar., 4441–4444). Results are presented of mechanical tests on a cast iron before and after heating to 550° C. to remove internal stresses. Internal stresses can be removed without affecting the mechanical properties of the iron.—B. C. W.

Some Problems Associated with Stress Concentration. H. L. Cox. (*J. Roy. Aeronaut. Soc.*, 1955, **59**, Aug., 551–561). A number of simple cases of stress and load concentration are considered and it is shown how the stress analysis is confirmed by static and fatigue tests. Some investigations into special two-dimensional boundaries are reported and some fairly general theoretical conclusions are made. Possible reasons why the theoretical conclusions do not always apply in practice are discussed.—B. G. B.

Investigation into the Failure of Two 100 MW Turbo-Generators. C. Gibb. (*Engineer*, 1955, **199**, Feb. 18, 236–237; Feb. 25, 272–273; Mar. 4, 296–298; Mar. 11, 355–356). This paper describes investigations into the failure of two generators

installed in the Richard L. Hearn generating station at Toronto. The author details some general considerations affecting the design of alternator rotors, the selection of materials used, past troubles which had to be avoided, reasons for certain features incorporated in the original design and modified as a result of the failures, and safeguards introduced into current practice to avoid the possibility of a repetition of the failures.—M. D. J. B.

Elastic Failure in Medium-Carbon Steel Tubular Specimens Subjected to Internal Pressure and Axial Loading. E. R. Leeman. (*J. S. African Inst. Mech. Eng.*, 1955, **4**, Apr., 297–308). The author reports the results of an investigation conducted on a South African mild steel. Thin-walled tube specimens, machined from the solid, were subjected to simultaneous axial tension and internal pressure. Two methods of applying the pressure were used, one in which the axial pressure force was resisted by the tube walls and the other in which this was not so. The results obtained are compared with some of the classical theories of failure and it is found that under the loading conditions applied they conform well with the maximum shear strain energy theory.—L. E. W.

Failure of a Large Welded Oil-Storage Tank. (*Brit. Welding J.*, 1955, **2**, June, 254–263). A report is given of an investigation on the failure of a large welded oil storage tank. The weld quality varied considerably. The fracture was of a typically brittle nature, starting at a defect in a repair, and then passed entirely through the unwelded parent plate material to the top and bottom of the tank. The careful investigation failed to reveal any indications of a shock, blow, or impact of any form.—U. E.

Creep Mechanism in Mild Steel. T. Nishihara and K. Tanaka. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1955, **7**, Mar., 10–12). [In Japanese]. Creep data are analysed graphically and mathematically. Experiments at 450° C. showed that strain recovery, on release of stress at given values, was approx. 0·2%, and equal to the elastic strain. On re-application of stress, the strain rate was increased considerably.—K. E. J.

Influence of Grain Sizes of Metals on Fatigue Failures, Especially under Rolling Contact. T. Nishihara and K. Endo. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1954, **5**, Mar., 11–16). [In Japanese]. The influence of the grain size of steel on the ' micro-Poisson's constant ' was studied through bending and torsional fatigue tests. Endurance tests under rolling contact were made, using steels of varying grain sizes. The influence of grain size on pitting strength was investigated, and the effect of stress gradient on notch sensitivity is discussed.

Researches on Fatigue Deformation. M. Kawamoto and K. Nishioka. (*Mem. Fac. Eng. Kyoto Univ.*, 1954, **16**, Oct., 228–252). Bending and torsional fatigue tests were made on carbon and spring steels, and various aspects of fatigue deformation, depending on the value of the applied stress, are described. Under some circumstances a step-wise increase in deformation of mild steel is observed. Preliminary plastic working decreases the subsequent degree of fatigue deformation.—K. E. J.

Researches on Fatigue under Consideration of the Phenomenon of Elastic Hysteresis. M. Kawamoto and K. Nishioka. (*Mem. Fac. Eng. Kyoto Univ.*, 1955, **17**, Jan., 1–29). [In English]. The relation between form and notch factors can be derived theoretically, taking elastic hysteresis into account. From torsional fatigue tests on C steels, the relationships between notch factor and the sharpness of the notch were obtained, and agree with theoretical predictions.—K. E. J.

Change of Internal Friction Due to Metal Fatigue. H. Miki. (*Bull. Eng. Res. Inst. Kyoto Univ.*, 1952, **1**, Mar., 15–19). [In Japanese]. The logarithmic decrement due to internal friction is also influenced by the measurement frequency, and observations over a wide range of frequency are needed to assess the internal state of the metal adequately. From rotating-bending fatigue tests on 0·1% C steel wire rod, it is concluded that the intercrystalline strain gradient induced by repeated stress is more important than structural imperfections in producing fatigue failure.—K. E. J.

Application of Ultrasonic Flaw Detection Method for Cast Iron (Fatigue Test). H. Yamanouchi and T. Inukai. (*Waseda Univ., Rep. Castings Res. Lab.*, 1955, (6), 55–57). It was found possible to trace crack propagation in cast iron under repeated stress (in the rotating-beam fatigue test) using pulse techniques in the range 500 kc. to 1 Mc. The values of the attenuation constant varied with the intensity and frequency of repeated stress.—K. E. J.

Experiments in Fatigue Under Ranges of Stress in Torsion and Axial Load from Tension to Extreme Compression. W. N. Findley. (*Proc. Amer. Soc. Testing Mat.*, 1954, **54**, 836–852). Axial-load fatigue tests have been performed on SAE 4340 steel at mean stresses from 40,000 lb./sq. in. in tension to 135,000 lb./sq. in. in compression (a stress equal to the tensile strength).—B. G. B.

Elevated-Temperature Fatigue Properties of Several High-Temperature Sheet Materials. D. C. Goldberg and J. J. Lombardo. (*Proc. Amer. Soc. Testing Mat.*, 1954, **54**, 324–334).

Cumulative Damage in Fatigue—A Method of Investigation Economical in Specimens. J. C. Levy. (*Engineering*, 1955, **179**, June 10, 724–726). The author presents a new method of treating fatigue-test results. On the assumption that the scatter of a series of results is due to local conditions pre-existing within each particular specimen, it has been presumed that a specimen which showed an unduly long, or an unduly short, life under one applied stress would have shown a similarly long or short life under a different level of stress. Thus a one-to-one correspondence has been assumed between the lives of individual specimens in sets of tests performed under different conditions. This has allowed each test result to be utilized separately, enabling a greater amount of information to be obtained from a limited number of tests than if only mean, or median, values were used. Another advantage is that the proposed method is not dependent on the life-distribution function at any particular stress level.

Short-Time Creep-Relaxation Tests—Effect of Methods of Loading. S. J. Watson. (*Engineering*, 1955, **179**, May 6, 565–566). The tests described were made to determine whether the initial straining procedure had any effect on the creep/relaxation curves subsequently obtained.—M. D. J. B.

Creep-Relaxation Testing—Tests at Constant Strain and Decreasing Load. J. H. M. Draper. (*Engineering*, 1955, **179**, May 6, 564–565). This article discusses briefly the principles and problems of relaxation testing.—M. D. J. B.

10-Ton Fatigue Testing Machine. H. L. Cox and M. B. Owen. (*Engineering*, 1955, **179**, Apr. 22, 500–504). This article describes a 10-ton mechanical fatigue-testing machine which operates at the resonant of a mass-spring system, at about 2000 cycles/mm. The machine has completed over 650 million stress cycles, mainly in tests on chains under pulsating loads. The results of the tests on short-link ¾-in. and 1-in. dia. wrought-iron chains are included.—M. D. J. B.

Design of a Comprehensive Computer for Handling Complex Creep Problems. A. J. Kennedy. (*Engineer*, 1955, **200**, July 1, 2–4; July 8, 34–35). This paper reviews the problem of creep under conditions where stress and temperature are not kept constant, and examines the possibility of computing the behaviour fairly rapidly from the minimum experimental data.—M. D. J. B.

Mechanics of Creep. J. Hult. (*Tekn. Tidskr.*, 1955, **85**, Mar. 8, 199–204). [In Swedish]. A review of elementary creep mechanics deals with past research into its physical aspects, typical results of creep measurements, the phenomenon of relaxation, nature of primary and secondary creep, and the application of creep relationships on the basis of constant and variable stress.—G. G. K.

Metal Fatigue. State of Our Present Knowledge. (*Usine Nouvelle*, 1955, **11**, June 9, 62–65; June 16, 27–29). This paper presents a study of research work concerning this inadequately understood phenomenon. Its mechanism, effect of repeated stress on the metal, influence of state of the surface, and effect of surface hardening are studied.—T. E. D.

Fatigue Strength of Flame-Cut Specimens in Black Mild Steel. F. Koenigsberger and H. W. Green. (*Brit. Welding J.*, 1955, **2**, July, 313–321). An investigation was carried out to determine fatigue properties of black mild-steel flame-cut specimens. It is shown that the heating effect of the cutting process has no greater influence on the fatigue resistance than the presence of the scale inherently present on mild steel. Normalizing does not appear to improve the fatigue resistance of flame cut specimens.—U. E.

Fatigue and the Comet Disasters. T. Bishop. (*Metal Progress*, 1955, **67**, May, 79–85).

The Effect of Various Fits on the Fatigue Strength of Pin-Hole Joints. A. Hartman and F. A. Jacobs. (*Nat. Aeronaut. Res. Inst.*, 1954, Report M 1946). It appears that a joint with a hard-drive fit has a higher fatigue strength than a

joint with a clearance fit or a tight fit. The effect of the fit of a pin-hole joint on the distortion of the hole at static load was also determined.—B. G. B.

Anisotropy of Fatigue Strength of a Steel and Two Aluminium Alloys in Bending and in Torsion. W. N. Findley and P. N. Mathur. (*Amer. Soc. Test. Mat.*, Preprint, 1955, No. 75). A similar variation of the fatigue strength with orientation relative to the texture was observed for all three metals. The fatigue strength in bending decreased as the orientation changed from longitudinal to diagonal to transverse; the fatigue strength in torsion was nearly constant in all three orientations.—B. G. B.

An Axial Loading Creep Machine. M. H. Jones and W. F. Brown. (*Amer. Soc. Test. Mat.*, Preprint, 1955, No. 89). Factors influencing the eccentricity of loading in tension testing are discussed. A design of machine is described for creep testing under tension in which bending stresses are reduced to a minimum.—B. G. B.

Understressing as a Means of Eliminating the Damaging Effect of Fatigue Stressing. H. E. Frankel and J. A. Bennett. (*Amer. Soc. Test. Mat.*, Preprint, 1955, No. 71). Rotating-beam tests on a heat-treated alloy steel showed that the fatigue limit could be increased by coaxing. The damaging effect of fatigue stressing 10% above the fatigue limit was eliminated by understressing and coaxing. Damage produced by 30% stress above the fatigue limit was not completely eliminated. Specimens coated with a rust-preventive oil showed greater fatigue resistance than clean specimens.

Dislocation Theory of the Fatigue Fracture of Ductile Metals. F. E. Fujita. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1954, A, **6**, Dec., 565–572). A dislocation model of the fatigue fracture of ductile models is proposed, based on two parallel unlike rows of edge dislocations 10Å. or less from each other.

The Theory of Fatigue Fracture of Metals. T. Yokobori. (*J. Phys. Soc. Japan*, 1955, **10**, May, 368–374). A theory, which is in qualitative agreement with experimental data, is devised based on the assumption of a fatigue crack forming as the consequence of a tensile stress arising from a dislocation pile-up being reinforced by an externally applied tensile stress component. Scatter in the number of cycles to fracture is largely accounted for as a stochastic phenomenon associated with the nucleation process of crack formation. The dependence of the theoretical fatigue strength on temperature is in fair agreement with published data.—J. G. W.

ANALYSIS

Spectrographic Determination of Residual Elements in Steel. Spectrographic Analysis Sub-Committee of B.I.S.R.A. (*J. Iron Steel Inst.*, 1955, **181**, Dec., 316–318). [This issue].

INDUSTRIAL USES AND APPLICATIONS

High Alloy Castings in Heat Treating Resist High Temperature Conditions. (*Indust. Heating*, 1954, **21**, Oct., 1999–2006). The applications of cast alloy steels containing Cr, Ni, and balance Fe for intermittent service at 1200° F. are described. These alloys are used for annealing boxes, recuperators, and muffles.—A. D. H.

Permissible Stresses in Crane Structures. Review of European Specifications. W. Lo Varco. (*Costruzioni Met.*, 1954, **6**, Nov.-Dec., 33–39). [In Italian]. A comparison is made between the specifications for crane structures operative in Britain, France, Germany, and Italy, with particular reference to alternating and impact stresses.—M. D. J. B.

Metallurgical Progress and the Chemical Industry. M. Cook. (*Chem. Indust.*, 1955, Apr. 2, 366–376). The production and use of metals, particularly in the chemical industry, is surveyed. Steel, cast iron, aluminium, copper, and titanium are dealt with in detail, and also the coating and joining of metals and the significance of alloy additions. Forecasts of future output and applications are included.—J. O. L.

Testing Sandvik Coromant Drill Steels in the Bodås Mine, Sweden. E. Hjelmquist and G. Karlstrom. (*Min. J.*, 1955, **244**, Mar. 11, 266–267). The techniques used for testing tungsten carbide tipped drills with particular reference to the behaviour of the drill steels manufactured by the Sandvik Steel Works Company are described.—B. G. B.

Sectional Design Simplifies the Construction of Dies. F. Strasser. (*Tecn. Indust.*, 1955, **33**, Jan., 54). [In Spanish]. A die for the production of circular cutters possessing two different sections was required. Greater economy and precision resulted from building the die in sections instead of making it in one piece. The method used in this particular project is illustrated.—P. S.

Press-Fitting. A. Jenaro Garrido. (*Dyna*, 1955, **30**, Feb., 116–122). [In Spanish]. A discussion on the merits of fitting together parts by pressure is given. The radial pressure in the contact surface, and the tangential tensile stresses in the interior are calculated and plotted graphically as a function of differences in diameter of the two parts and their radii of contact, for steel and cast iron. The forces required for press-fitting are derived mathematically and the effect upon them of various factors is illustrated in tabular form.—P. S.

Steels for Ball Bearings. M. Pujol Roig. (*Rev. Cienca Apl.*, 1954, **8**, Sept.-Oct., 404–415; Nov.-Dec., 507–521). [In Spanish]. The fabrication, desirable properties, casting and working defects likely to be encountered, and the inspection of steels suitable for bearing purposes are discussed. The forging and heat-treatment of these steels are considered. Isothermal heat-treatments are considered together with their advantages and disadvantages. Forty commercial bearing steels are listed with a comparison of their fractures, grain sizes, hardnesses, and microstructures.—P. S.

Metallurgical Progress and the Steam Engineer. L. Sanderson. (*Steam Eng.*, 1955, **24**, Feb., 159–161). More than 20 important metallurgical advances of direct and potential interest to the steam engineer are briefly described.—T. E. D.

Sandwich Structures. J. V. Long and G. D. Cremer. (*Aircraft Prod.*, 1955, **17**, Jan., 22–31). The field of application of all-metal honeycomb structures for various high temperature uses is surveyed. The honeycomb sandwiches have skins of 0·01–0·03 in., and the core is built up of 0·001–0·01 in. stock by brazing or resistance welding. Various corrosion resistant and high-temperature alloys have been used, and performance is improved by fluid cooling or by filling with refractory.—T. E. D.

HISTORICAL

Georgius Agricola. H. R. Schubert. (*J. Iron Steel Inst.*, 1955, **181**, Dec., 319). [This issue].

BOOK NOTICES

ROBIETTE, A. G. E. "*Electric Melting and Smelting Practice.*" La. 8vo, pp. vii + 347. Illustrated. London, 1955: Charles Griffin and Co., Ltd. (Price 50*s.*).

A glance at the bibliography appended to this book shows clearly the extent of a subject upon which Mr. Robiette has ventured for a second time during the last twenty years.

The very complexity of this subject makes it difficult to present in a single volume more than a comparatively brief description of each major branch of electric melting and smelting practice. Nevertheless the author has succeeded admirably and the 300-odd pages of his book are crammed with facts and figures presented in an easy, intelligible style.

An important section of this book deals with the arc melting furnace, the leading types of which are described in detail. Many engineers since the days of Werner von Siemens and Paul Héroult have devoted their talents to the improvement of arc furnace design. Metallurgists, by contributing courage and skill, have enabled units of a size undreamed of a few years ago to be put into successful operation. It is little wonder therefore, that such technical matters as automatic electrode control and top charging—to name but two—have proved extremely controversial. The author, therefore, has wisely confined himself to factual descriptions and does not attempt to justify any of the claims made on behalf of one or other method.

Induction melting furnaces are described with sufficient theoretical detail to explain the basic design of both high-frequency coreless and mains-frequency channel type units.

Such is the pace of modern technical development, however, that no mention is made of a complementary induction furnace—namely, the mains-frequency coreless type. This has made considerable progress on the Continent in the last two or three years and has also recently been introduced into this country; it appears to hold out considerable promise for the future in certain fields of application, notably the iron foundry, and it is a pity that the author did not devote a few paragraphs to complete his excellent section on induction melting.

There are very few books available in English dealing with the fascinating subject of electric smelting. Mr. Robiette has rendered a great service to all interested in electric furnaces by describing in some detail the metallurgical aspect of smelting as well as the practical side of furnace construction. This is an excellent book not only for students but also for all metallurgists, foundrymen, or engineers who require a concise guide in this field.—F. S. LEIGH.

SMITHELLS, COLIN J. "*Metals Reference Book.*" 2nd edition, in two volumes. La. 8vo, illustrated. Vol. I, pp. xvi + 531 + 17; vol. II, pp. xv + 533–967 + 17. London, 1955: Butterworth's Scientific Publications. (Price £8 8*s.* 0*d.* (two volumes)).

Excellent as was the first edition of this "Metals Reference Book," this second edition is a considerable improvement, and its scope is much wider than the title suggests. Besides sections detailing metallurgical data there are sections devoted to geochemistry, to lubricants, to friction, to fuels, and to carbon and graphite electrodes. It is quite different from "Metals Handbook," published by the American Society for Metals, in that most of the data are presented in the form of tables or diagrams, although where necessary short monographs have been included. Some sections have been entirely rewritten, i.e. those on crystal chemistry, diffusion in metals, thermochemical data, and welding, and new sections have been added, viz. those covering elastic properties and damping capacity, physical properties of molten salts, and friction. There is one section of the book that has not, however, been brought up to date, and that is the one dealing with casting alloys and foundry data, in which no reference is made to two important developments, viz. shell moulding and the CO_2 process.

The size of the book has been increased by the inclusion of a more complete bibliography, and it has been necessary to publish it in two volumes; a convenient feature is that each volume concludes with a complete index to both volumes. Eight guineas is a lot of money for this publication, but it does contain in a compact form practically all the data that are ever required by anyone working on problems involving the manufacture or use of any metal.

J. FERDINAND KAYSER.

NEW PUBLICATIONS

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